



## **BLAST RESISTANT AND BLAST DIRECTING CONTAINER**

### **ASSEMBLIES**

### **RELATED APPLICATIONS**

This is a continuation-in-part of pending Application No. 08/533,589, filed September 25, 1995.

### **BACKGROUND OF THE INVENTION**

#### 5    **1. Field of the Invention**

The present invention relates to container assemblies. More particularly, this invention relates to various blast resistant and blast directing container assemblies for receiving explosive articles and preventing or minimizing damage in the event of an explosion. These container assemblies have utility as containment and transport devices for hazardous materials such as gunpowder and explosives, e.g., bombs and grenades, particularly in aircraft where weight is an important consideration, and more particularly in the cargo holds and passenger cabins of the aircraft. They are also particularly useful to bomb squad personnel in combating terrorist and other threats.

#### 15    **2. The Prior Art**

In response to the 1988 terrorist bombing of a Pan American flight over Lockerbie, Scotland, experts in explosives and aircraft-survivability techniques have studied ways to make commercial airliners more resistant to terrorist bombs. One result of these studies has been the development and deployment of new generations of explosive detection devices. As a practical matter, however, there remains a threshold bomb size above which detection is relatively easy but below which an increasing fraction of bombs will go undetected. An undetected bomb likely would find its way into luggage either carried on board (in cabin) by a passenger or stored in an aircraft cargo container. Cargo containers, shaped as cubic boxes with a truncated edge, have typically been made of aluminum, which is lightweight but not explosion-proof. As a consequence, there has been tremendous focus in recent years on redesigning containers to be both blast resistant to bombs that are below this threshold size and lightweight.

A good overview on redesigned aircraft cargo containers is found in  
30    Ashley, S., SAFETY IN THE SKY: Designing Bomb-Resistant Baggage

Containers, Mechanical Engineering, v 114, n 6, Jun 1992, pp 81-86, hereby incorporated by reference. One type of container disclosed by this article is designed to suppress shock waves and contain exploding fragments while safely bleeding off or venting high pressure gases, while another type is designed to guide  
5 explosive products overboard by channeling blast forces out of and away from the airplane hull. Several of the new designs utilize composite materials that are both strong and lightweight. In one such design, a hardened luggage container is wrapped in a blanket woven from low density materials such as SPECTRA® fibers, commercially available from AlliedSignal Inc., and lined with a rigid  
10 polyurethane foam and perforated aluminum alloy sheet. A sandwich of this material covers four sides of the container in a seamless shell. In this regard, see also U.S.P. 5,267,665, hereby incorporated by reference.

Access to a container's interior is necessary for loading and unloading and is typically provided by doors. Doors provide a significant weak point for the  
15 container during an explosion since a blast from within the container forces a typical door outward. If the door is connected through a hinge and metal pin arrangement, the pins become dangerous projectiles. If the door slides in grooves or channels, the grooves or channels may bend or distort to cause failure of the container. It would thus be desirable to have a container design that eliminates the  
20 aforesaid problems with doors for access to the container's interior.

U.S.P. 5,312,182 discloses hardened cargo containers wherein the door engages by sliding in grooves/tracks with an interlock that ostensibly responds to such an explosive blast by gripping tighter to resist rupture of the device. Other blast resistant and/or blast directing containers are described in European Patent  
25 Publication 0 572 965 A1 and in U.S.P. Nos. 5,376,426; 5,249,534; and 5,170,690. All of these publications are hereby incorporated by reference.

Containers for storing and/or transporting explosives such as bombs, or suspected explosives, are also known. See, for example, U.S.P. Nos. 5,225,622; 4,889,258; 4,432,285; 4,055,247; 4,027,601; and 3,786,956, all hereby  
30 incorporated by reference. These containers are typically made of a high strength outer housing having a fixed shape and containing a structure for supporting the

explosive out of contact with the housing. High strength materials taught for forming the outer housing include metal, such as stainless steel or steel plate, and ballistic fiberglass. Supporting structures taught include vermiculite in a binder, foamed plastic (such as styrofoam), foam rubber, and cardboard. The containers  
5 generally are heavy and have a bulky, fixed shape or construction.

The environment in which a container is to be used may have weight and space constraints, for example, the passenger cabin or cargo hold of an aircraft. Such constraints make desirable a collapsible container that folds into a compact shape for storage when not in use.

10 The present invention, which was developed to overcome the deficiencies of the prior art, provides blast resistant and blast directing container assemblies, some of which are collapsible.

#### **BRIEF DESCRIPTION OF THE INVENTION**

This invention is a blast resistant container assembly for receiving an  
15 explosive. The container assembly comprises a container, collapsible when empty, of blast resistant material. A blast mitigating material is located within the container.

In another embodiment the blast resistant container assembly comprises at least three bands, one of which preferably comprises a blast resistant material, and  
20 blast mitigating material. A first inner band is nested within a second band which is nested within a third band, with all bands being oriented relative to one another to substantially enclose a volume and to form a container wall having a thickness substantially equivalent to the sum of the thicknesses of at least two of the bands. The blast mitigating material is located within the inner band.

25 In a particularly preferred embodiment the blast resistant container assembly comprises at least three collapsible, seamless bands of a blast resistant material and an aqueous foam. The blast resistant material comprises high strength fibers having a tenacity of at least about 10 g/d and a tensile modulus of at least about 200 g/d. The bands are nested one within the other when assembled with  
30 their longitudinal axes at right angles to one another to substantially enclose a volume and to form a container wall having a thickness substantially equivalent to

the sum of the thicknesses of at least two of the bands. The bands are collapsible for storage when disassembled. The inner band preferably includes a foldable flap forming a lip on each side thereof and is stabilized to prevent twisting. The inner band can be stabilized by consolidation if it comprises a composite material or by affixing rigid plates or other support structure thereto if not susceptible to consolidation. The aqueous foam located within the inner band preferably has a density in the range of from about 0.01 to about 0.10 g/cm<sup>3</sup>, more preferably in the range of from about 0.03 to about 0.08 g/cm<sup>3</sup>. This embodiment is particularly useful as an aircraft in-cabin emergency containment system.

10 In an alternate embodiment, the present invention is a blast resistant container assembly for receiving an explosive wherein the container assembly comprises a container having an access opening; blast mitigating material located within the container; and at least one band of a blast resistant material. The band slides over the container in a first direction to encircle the container and at least partially cover the access opening, and in a second direction to at least partially expose the access opening. The band or bands together preferably cover at least about 50 percent, more preferably at least about 80 percent, and most preferably all, of the surface area of the access opening if there is no door for the access opening. If a door is included for the access opening, then the band at least partially covers the surface area of the door when the door is closed over the access opening. It is preferred that at least about 20 percent, more preferably at least about 40 percent, and most preferably about 60 percent, of the surface area of the door be covered by the band or bands together. This embodiment is particularly useful for the containment and removal of explosives found by detection or screening devices, for example, in airports.

In yet another aspect, the present invention is a blast directing container assembly for receiving an explosive wherein the container assembly comprises at least one closed band of blast resistant material and blast mitigating material located within the band. The band has two open sides, and the blast resistant material comprises a network of high strength fibers wherein at least about 50,

more preferably about 75, weight percent of the fibers comprise continuous lengths in the direction of the band.

The three band box design of the preferred container assembly of this invention has several advantages over containers of the prior art. It eliminates the need for an entry door since access can be achieved through an open side or sides of the innermost band. This eliminates one of the weak points of the prior art containers: door and panel hinges with steel rods are no longer necessary and neither are door-channel interlock systems. Other modifications permit easy access to the container's interior for loading and unloading in spite of limited exterior space constraints. The box is not impervious to explosive's gas and allows controlled release of the gas through the corners which contributes to the design function. The box production is technology inexpensive and simple. The bands of the box can be made rigid or flexible as desired. If the bands of the box are made with flexible edges and rigid faces, then they can be collapsed for more efficient storage and transported as a set of three or more essentially flat parts (bands) for subsequent assembly and use with the blast mitigating material.

Blast mitigating materials can absorb heat energy from the blast by an increase in temperature, phase transition, e.g., vaporization of water). They may collapse and absorb energy by crushing and/or visco-elastic effects. Condensable gases (in foams) may condense under elevated pressure, thereby liberating heat of condensation to the aqueous phase. Condensable gases will cause a decrease in shock wave velocity and through condensation transmit heat energy. Kinetic energy can be imparted to all of these materials.

The use of aqueous foam with condensable gas as a foaming agent significantly lengthens the time of venting and reduces the hazard. As such, it is a preferred blast mitigating materials.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will be more fully understood and further advantages will become apparent when reference is made to the following drawing figures and the accompanying description of the preferred embodiments wherein:

FIGURE 1A is a three dimensional view of band 11 which forms part of container assembly 10 of FIGURE 1F;

FIGURE 1B is a three dimensional view of band 12 which forms part of container assembly 10 of FIGURE 1F;

5        FIGURE 1C is a three dimensional view of band 13 which, when filled with blast mitigating material 14 and assembled with bands 11 and 12, constitute container assembly 10 of FIGURE 1F;

FIGURE 1D is a three dimensional partial assembly view which together with FIGURE 1E illustrates the assembly sequence for container assembly 10;

10        FIGURE 1E is a three dimensional partial assembly view which together with FIGURE 1D illustrates the assembly sequence for container assembly 10;

FIGURE 1F is a three dimensional assembly view of container assembly 10;

FIGURE 1G is a three dimensional view of an optional support structure 17 for inclusion in the assembly of container assembly 10;

15        FIGURE 2A is a three dimensional view of alternate band 12' with flaps X and Y;

FIGURE 2B is a three dimensional partial assembly view that illustrates the assembly sequence for container assembly 10';

FIGURE 2C is a three dimensional assembly view of container assembly 20    10';

FIGURE 3A is a three dimensional view of alternate band 11'' cut at corners 16 to create portions which when folded will create lips 18;

FIGURE 3B is a three dimensional view of alternate band 11'' with lips 18;

FIGURE 3C is a three dimensional partial assembly view that illustrates the 25    assembly sequence for container assembly 10'';

FIGURE 4 is a three dimensional assembly view of container assembly 10''';

FIGURE 5A is a three dimensional view of alternate band 11'''' which is hexagonal in cross-section;

30        FIGURE 5B is a three dimensional partial assembly view of alternate bands 11'''' and 12'''';

FIGURE 5C is a three dimensional assembly view of container assembly 10'''';

FIGURE 6A is a three dimensional partial assembly view that illustrates a two part (M and N) equivalent to band 12 for use with container assembly 10'''' of the present invention;

FIGURE 6B is a three dimensional partial assembly view similar to FIGURE 6A but adding third band 13'''';

FIGURE 6C is a three dimensional assembly view of container assembly 10'''';

FIGURE 7A is a three dimensional assembly view of a blast resistant container assembly 20 in the closed/loaded position;

FIGURE 7B is a three dimensional assembly view of container assembly 20 in the open/loading position;

FIGURE 8A is a three dimensional view of an inner shell 31 for a blast resistant container with loading/unloading capabilities when in restricted space;

FIGURE 8B is a three dimensional partial assembly view of container assembly 30;

FIGURE 8C is a three dimensional partial assembly view of container assembly 30;

FIGURE 8D is a three dimensional view of bands 40 and 41 for use in assembly 30;

FIGURE 8E depicts the container assembly 30 in the closed (loaded) position;

FIGURE 8F depicts the container assembly 30 in the open (loading/unloading) position;

FIGURE 9A is a three dimensional view of band 50 with rigid inserts prior to folding to create lips 18';

FIGURE 9B is a three dimensional partial view of band 50 with rigid inserts prior to folding to create lips 18';

FIGURE 9C is a three dimensional partial view of band 50 during folding;

FIGURE 9D is a three dimensional partial view of folded band 50;

FIGURE 9E is a three dimensional view of folded band 50;

FIGURE 10A is a three dimensional view of a disassembled in cabin container assembly kit 60;

FIGURE 10B is a three dimensional view of the partially open band 63;

5 FIGURE 10C is a three dimensional view of the fully open band 63;

FIGURE 10D is a three dimensional view of open inner band 62 with luggage 61 placed therein;

FIGURE 10E is a three dimensional view of band 63 being placed on the loaded inner band 62;

10 FIGURE 10F is a three dimensional view of band 64 being placed on nested bands 62 and 63;

FIGURE 10G is a three dimensional view of the assembled in cabin container assembly 70;

15 FIGURE 10H is a three dimensional view of band 62 with net 69 attached thereto;

FIGURE 10I is a three dimensional view of container assembly 70 with optional carrying devices;

FIGURE 11A is a three dimensional view of blast directing tube 90 of the present invention with blast mitigating material 14 therein; and

20 FIGURE 11B is a three dimensional view of an alternate blast directing tube 95 of the present invention with blast mitigating material 14 therein.

### **DETAILED DESCRIPTION OF THE INVENTION**

The preferred invention will be better understood by those of skill in the art with reference to the above figures. The preferred embodiments of this invention  
25 illustrated in the figures are not intended to be exhaustive or to limit the invention to the precise form disclosed. It is chosen to describe or to best explain the principles of the invention and its application and practical use to thereby enable others skilled in the art to best utilize the invention. In particular, the bands of blast resistant material are shown in the accompanying drawings with parallel lines  
30 representing substantially continuous fibers/filaments in the hoop direction of the bands, i.e., as unidirectional fibrous bands. This representation is for ease in



understanding the invention - while it constitutes one fabric contemplated for use in the present invention, it is not the exclusive fabric.

Initial discussion of the drawing figures will be directed to design considerations followed by a discussion of appropriate materials and how they affect blast resistance and/or blast directing capabilities of the structures.

Referring to FIGURE 1F, the numeral 10 indicates a blast resistant container assembly. The construction of container assembly 10 is critical to the advantages of this invention. The container comprises a set of at least three nested and mutually reinforcing four-sided continuous bands of material 11, 12, and 13 assembled into a cube. See FIGURES 1A, 1B, and 1C. By "band" is meant a thin, flat, volume-encircling strip. The cross-section of the encircled volume may vary, although polygonal is preferred to circular, with rectangular being more preferred and square being most preferred, as depicted. With reference to FIGURES 1D and 1E, a first inner band 11 is filled with blast mitigating material 14 (depicted as an aqueous foam) and then nested within a slightly larger second band 12 which is nested within a slightly larger third band 13, all bands with their respective longitudinal axes perpendicular to one another. In this fashion, each of the six panels forming the faces of the cubic container will have a thickness substantially equivalent to the sum of the thicknesses of at least two of the bands 11, 12 and 13, where they overlap, and every edge 15 of the container is covered by at least one band of material, 11, 12, or 13. Stated differently, after the load (explosive or luggage) is placed in the first band 11, blast mitigating material 14 is placed or dispersed around the load within the first band 11. The second structurally similar band 12 of slightly larger dimensions is placed over the first so that its longitudinal axis is perpendicular to that of first band 11 (see FIGURE 1D). The third, similar yet larger, band 13 is slid over the second band 12, so that its longitudinal axis is perpendicular to the axes of both bands 11 and 12 (see FIGURE 1E). The third band 13 completes the preferred blast resistant container assembly 10. The fit between bands 11, 12 and 13 is not intended to be a gastight seal, but is a close fit to permit gas to vent gradually, in the event of an explosion, from the corners 16 of the cubic container. It is preferred that the bands slide on one another, and

therefore the frictional characteristics of their surfaces may need to be modified, as will be discussed in more detail later. Container assembly 10 does not have a separate entry door and thus avoids all of the limitations presented by the same in the prior art. FIGURE 1G depicts a weight/load bearing frame 17 which may optionally be nested within container assembly 10 in the event that container assembly 10 is insufficiently rigid for bearing the items to be loaded therein. Inner band 11 is slipped over the frame initially, and then assembly proceeds as earlier discussed. Frame 17 may be made from metal or structural composite rods designed in a way to optimize the load bearing capacity of the structure and to minimize container weight.

In a variation on the basic design, second band 12 is replaced by band 12', which is a five-sided, discontinuous strip (see FIGURE 2A), i.e., band 12' comprises five substantially rectangular, preferably square as depicted, surfaces in series, which is one more than the four sides forming the rectangular cross-section thereof. Bands 11 and 13 and blast mitigating material 14 are the same as in the basic design. With reference to FIGURE 2B, band 12' is wrapped around filled inner band 11 with its first and fifth sides overlapping at one of the open sides of first band 11 to create flaps X and Y. Third band 13 completes the blast resistant container assembly 10'. Access to one side of cubic container assembly 10' is achieved by removal of band 13 and opening flaps X and Y. In this embodiment, band 12' preferably is a nested band to prevent flaps X and Y being blown open during an explosion. Container assembly 10' does not have a separate entry door and thus avoids all of the limitations presented by the same in the prior art.

With reference to FIGURES 3A, 3B AND 3C which depict another variation on the basic design, inner band 11 is replaced by inner band 11'' which has lips 18 formed on both sides thereof prior to being filled with blast mitigating material 14 and subsequent assembly with the other bands 12 and 13. Band 11'' can be made wider than needed, cut at each corner 16, and folded to create lips 18 on each side (see FIGURES 3A and 3B). Lip 18 is a projecting edge or small flap which is substantially perpendicular to the plane of band 11'' in use - the next outermost band (in this instance band 12) will hold flap 18 in this relationship to

band 11''. The presence of lips 18 during an explosion of the container serves to limit the rate at which hot gases escape from the container after an explosion; this serves to prevent damage to nearby people and property, as well as to decrease the danger of the container catching fire. Any inside band can be formed with lips;  
 5 however, best results are obtained with the lips 18 on the innermost band 11''.

Many differing container shapes are contemplated by the present invention. For instance, the container assembly 10''' of FIGURE 4 encloses a non-cubic rectangular prism due to the differing rectangular cross-sections of its three bands. In FIGURE 5C is shown container assembly 10'''' formed by a first inner band  
 10 11'''' (see FIGURE 5A), substantially hexagonal in cross-section, filled with blast mitigating material 14 and nested in four-sided band 12'''' (FIGURE 5B), which is nested in four-sided band 13''''', which is nested in four-sided band 14'''''. The preference for the bands to have a polygonal cross-section is derived from the tendency for the container to deform to increase the internal volume during an  
 15 explosion.

It should be appreciated by now that substantially more than three bands can readily be utilized in the present invention, even with the basic cube (or rectangular prism) design of the container. With reference to FIGURES 6A, 6B, and 6C, which depict cubic container assembly 10''''', second band 12'''' is split  
 20 by design into two identical parallel and coaxial parts M and N in which inner band 11'''' is nested (or, which are placed over inner band 11'''''). The assembly of band 11'''' is with smaller parts (bands) M and N nested in outer band 13'''''. Such a container assembly 10'''' would be much easier to load and unload than a comparable container assembly 10 of standard aircraft size, i.e., 6x6x6 ft. By way  
 25 of example, loading takes place when the first band 11'''' is placed on a beam by a conventional lifting fork. Subsequently first band 11'''' is see-sawed up for band M to be placed around it. Band 11'''' is then stabilized for items 19 to be loaded onto first band 11'''''. After loading, band 11'''' is then filled with blast mitigating material 14 and then see-sawed in the other direction to permit band N  
 30 to be placed therearound. Thereafter the assembly is stabilized and band 13'''' is placed over the assembled bands as shown in FIGURES 6B and 6C. The

procedure is reversed for unloading container 10'''''. Intermediate parts (bands) M and N do not have to be removed entirely for unloading, and can be slid in whatever direction is preferred, i.e., in opposition to one another, as depicted, or in the same direction. They can also be arranged to telescopically slide in the same  
5 direction. Outer band 13'''''' could similarly be made out of two or more sections as desired.

Theoretically an unlimited number of coaxial bands can be used in parallel, preferably abutting one another, to substitute for any one band in the basic three-band container concept of the invention. On the inner band equivalent, all of the  
10 coaxial bands can have lips (e.g., see FIGURE 3B) or overlapping flaps (e.g., see FIGURE 2B). On the intermediate band equivalent, all of the coaxial bands can have flaps but only those adjacent the edge can have a lip on the side adjacent to the edge. It is preferred that the outermost band comprises a single continuous band. Furthermore, a large number of coaxial bands can also be coaxially nested  
15 one within the other to substitute for any one band in the basic three band container concept of the invention; the number of bands utilized as an equivalent may depend upon the desired rigidity of the equivalent. It is possible to have several flexible bands which, when nested coaxially, become rigid.

FIGURES 7A and 7B depict a blast resistant container assembly 20 that  
20 addresses the issue of an effective closure. Container assembly 20 can be a container of the prior art with an access opening on one or more sides thereof, or it can be a container with two bands of the three-band concept already discussed and having an access opening on one or more sides thereof. FIGURE 7B depicts container assembly 20 in the open position for loading or unloading. Flap door 21  
25 provides access to the interior from one side; there can be a similar access on one or more of the other side faces. In FIGURE 7B, the explosive (not shown) and blast mitigating material 14 have already been loaded. It is preferred that both the door and the container be formed of a rigid material, which will be detailed later. A band 22, preferably square in cross-section, is slipped onto container 20 to  
30 encircle its side faces and thereby secure closure of container 20 (see FIGURE 7A). Band 22 may cover all or only a small fraction of flap door 21 when closed.

At least about 20, preferably at least about 40, more preferably at least about 60, percent of the surface area of door 21 should be covered by band 22. Band 22 slides to one side of flap door 21, as depicted in FIGURE 7B, or completely off of the container to permit access through door 21. The shape of band 22's inner cross-section should conform to the portion of the container that it encircles. A polygonal cross-section is preferred with rectangular being more preferred and square (as depicted) being most preferred. Closure via this design is achieved without hinges (and the attendant, potentially lethal pins) or channels. During an explosion, band 22 holds door 21 in place. In the event that there was no door 21 covering the access opening, then at least about 50, preferably at least about 80, and more preferably substantially all, of the surface area of the access opening is covered by band 22.

FIGURES 8A-8F depict yet another blast resistant container assembly 30 which has loading and unloading capabilities when in a restricted space. This design is very similar to the three-band concept already discussed, which is very blast-containment effective. Modification to the three-band concept is necessary to provide convenient access to the interior of the container within the space constraints of an aircraft cargo hold. In FIGURE 8A is depicted a honeycomb core panel 31 which provides structural rigidity to the fully assembled container assembly 30. Panel 31 is essentially a cube with a truncated edge 32 and an opening 33 on one face that will provide the basis for access to the interior of container when assembled. A first inner band 34 is placed around panel 31 so that it covers opening 33. The material forming band 34, as will be discussed in detail later, is flexible and can be cut to create an upper 35 and a lower 36 access flap in band 34 at opening 33. The intermediate band 37 is a continuous strip/band under which floor panel 39 is attached (see FIGURE 8C). The outer band is a two-piece vertically sliding band consisting of sections 40 and 41 that can slide and telescope one 40 within the other 41 to open the container. Although it is preferred that sections 40 and 41 together completely cover flaps 35 and 36 when the container is closed, they may cover somewhat less than all of this area and still be effective. The interior of section 41 is sized slightly larger than the exterior of section 40 (see

FIGURE 8D) so that it can slide up over it to completely open access 33 as shown in FIGURE 8F. Stops 38 are provided on the side of the container. The rim on the bottom of stop 38 secures section 41 from falling down to the floor while the top of stop 38 secures section 40 from falling down inside of section 41. FIGURE 8E depicts the closed completely assembled container assembly. The telescoping feature of this design reduces the required extra space for loading or unloading to one-half that of the standard cubic box container. It would reduce the required extra space to one-third in the case of three telescoping sections, etc. Although more than three sections could theoretically be utilized, it would probably be impractical. The telescoping feature of this design could also be used in the closure embodiment depicted in FIGURES 7A and 7B utilizing containers of the prior art.

With reference to FIGURES 9A through 9E which depict another variation on the basic design, inner band 11 is replaced by inner band 50 which has lips 18' formed on both sides thereof prior to assembly. Band 52 can be made wider than needed and folded at its edges 15 to create lips 18' on each side. Lip 18' is a projecting edge or small flap which is substantially perpendicular to the plane of band 52 in use - the next outermost band will hold lip/flap 18' in this relationship to band 52. FIGURE 9A shows the use of reinforcing inserts for the inner band, i.e., a hardened square picture frame insert 51 for each of the four faces of the band, and the use of reinforcing inserts for the flaps on each side of the band, i.e., two hardened rectangular inserts 52 and two trapezoidal inserts 53. These inserts 51, 52, and 53 are spaced from one another to permit folding the flaps to form lips 18'. The flaps with trapezoidal inserts 53 oppose one another and are folded inward 90 degrees to form sides of a cube without having to cut the fabric along the edges between flaps. The flaps with rectangular inserts 52, which also oppose one another, are then folded inward 90 degrees and attached to the other flaps, e.g., by mating VELCRO® brand hook and loop type fasteners 54. The benefit of leaving the flaps/lip 18' uncut and connected is that they will be restrained from being flipped outward by the force of an explosion in the container assembly.

FIGURES 10A through 10I depict an aircraft in cabin emergency container assembly, in its disassembled kit form 60 (FIGURE 10A) through assembly

(FIGURES B through F) to an emergency container assembly 70 (FIGURE 10G). With reference to FIGURE 10A, kit 60 comprises collapsed (folded) bands 62, 63 and 64; a canister 66 of blast mitigating material, preferably an aqueous foam; optional telescoping pole 67; and belts 68 for holding kit 60 together while stored.

5 FIGURE 10B shows the unfolding of inner band 63 at its edges 15 until fully erect at FIGURE 10C. FIGURE 10D shows placement of suspect luggage 61 in the inner band 62 with closable flaps 65. With reference to FIGURE 10E, blast mitigating material 14, depicted as an aqueous foam, is dispersed into inner band 62 around suspect luggage 61 via canister 66. Flaps 65 are closed to form a lip,

10 and inner band 62 is nested within band 63 with their longitudinal axes perpendicular to one another. The third, similar yet larger, band 64 is slid over the second band 63 (see FIGURE 10F), so that its longitudinal axis is perpendicular to the axes of both bands 62 and 63. The in cabin container assembly 70 is shown in FIGURE 10G. FIGURE 10H shows the use of optional net 69 for holding the

15 suspect luggage 61' out of contact with the sides of bands 62 and 63. FIGURE 10I shows optional handles 71 through which telescoping pole 67 is placed for carrying the assembly 70. Handles 71 are taped (72) in place after assembly of container assembly 70.

The present invention is also concerned with blast directing containers and

20 tubes. FIGURE 11A depicts tube 90, which is a rigid, seamless, cylindrical band of blast resistant material, filled with blast mitigating material 14. Explosion of a charge placed in the center of tube 90 will discharge through the open ends of tube 90 in the direction of the arrows. A preferred cross-section of the tube would be rectangular, more preferably square. See tube 95 of FIGURE 11B and discussion

25 accompanying the examples further below. Several tubes/bands 96 of similar size and configuration could be coaxially arranged in an abutting relationship (see FIGURE 11C) for directing an explosive blast. Preferred construction would be similar to the bands 11'' of FIGURE 3B with lips 18 on either open side thereof. Optionally a single larger band could be placed around all of the tubes/bands, e.g.,

30 a single tube/band like that of FIGURE 11B could be placed around bands similar to those of FIGURE 11C. The larger band could be designed to encircle the open

ends and sides of the overall arrangement, if desired. As an alternative to the optional single larger band, one or more ropes (not shown) may be placed around all of the tubes. In both of these optional arrangements, the nature of the blast resistant material, as detailed below, is extremely important.

- 5           In the various embodiments depicted, a rigid inner liner or band can be constructed using one or more of the techniques and/or material to follow. The inner liner/band may be rotationally molded using polyethylene, cross-linkable polyethylene, nylon 6, or nylon 6,6 powders. Technology described in Plastics World, p.60, July, 1995, hereby incorporated by reference, can also be used.
- 10       Tubes, rods and connectors may be used, preferably formed from thermoplastic or thermoset resins, optionally fiber reinforced, or low density metals such as aluminum. The inner liner/band may utilize a continuous four-sided metal band. Sandwich constructions consisting of honeycomb, balsa wood or foam core with rigid facings may be used. The honeycomb may be constructed from aluminum,
- 15       cellulose products, or aramide polymer. Weight can be minimized by using construction techniques well known in the aerospace industry. (Carbon fiber reinforced epoxy composites may be used.) A rigid inner shell/band can be constructed from wood using techniques well known to the carpentry trades. (Flame retardant paints may usefully be used.) The rigid inner liner/band may serve
- 20       as a mandrel onto which the bands are wound and can form part of the final blast container. Alternatively the inner liner can be inserted into the inner band after the band has been constructed.

- As used herein with respect to bands, "rigid" means that a band is inflexible across the face or faces thereof. If the band comprises a plurality of faces and
- 25       edges, then it may be substantially inflexible across the faces but retain its flexibility at the edges and still be considered "rigid." Such a band is also considered "collapsible" since its flexible edges act as pin-less hinges connecting the substantially inflexible faces, and the band can be essentially flattened by folding at least two of its edges. With respect to the faces, flexibility is determined as
- 30       follows. A length of the material is clamped horizontally along one side on a flat support surface with an unsupported overhang portion of length "L". The vertical



distance "D" that the unclamped side of the overhang portion drops below the flat support surface is measured. The ratio D/L gives a measure of drapability. When the ratio approaches 1, the structure/face is highly flexible, and when the ratio approaches 0, it is very rigid or inflexible. Structures are considered rigid when  
5 D/L is less than about 0.2, more preferably less than about 0.1.

The structural designs of the present invention, especially the three band cube design, enhance the blast containment capability of the container. Blast containment capability is also enhanced with increased areal density of the container. The "areal density" is the weight of a structure per unit area of the  
10 structure in  $\text{kg/m}^2$ , as discussed in more detail in conjunction with the examples which follow below. The preferred blast resistant materials utilized in forming the containers and bands of the present invention are oriented films, fibrous layers, and/or a combination thereof. A resin matrix may optionally be used with the fibrous layers, and a film (oriented or not) may comprise the resin matrix.

15 Uniaxially or biaxially oriented films acceptable for use as the blast resistant material can be single layer, bilayer, or multilayer films selected from the group consisting of homopolymers and copolymers of thermoplastic polyolefins, thermoplastic elastomers, crosslinked thermoplastics, crosslinked elastomers, polyesters, polyamides, fluorocarbons, urethanes, epoxies, polyvinylidene chloride,  
20 polyvinyl chloride, and blends thereof. Films of choice are high density polyethylene, polypropylene, and polyethylene/elastomeric blends. Film thickness preferably ranges from about 0.2 to 40 mils, more preferably from about 0.5 to 20 mils, most preferably from about 1 to 15 mils.

For purposes of this invention, a fibrous layer comprises at least one  
25 network of fibers either alone or with a matrix. Fiber denotes an elongated body, the length dimension of which is much greater than the transverse dimensions of width and thickness. Accordingly, the term fiber includes monofilament, multifilament, ribbon, strip, staple and other forms of chopped, cut or discontinuous fiber and the like having regular or irregular cross-sections. The  
30 term fiber includes a plurality of any one or combination of the above.

The cross-sections of filaments for use in this invention may vary widely. They may be circular, flat or oblong in cross-section. They also may be of irregular or regular multi-lobal cross-section having one or more regular or irregular lobes projecting from the linear or longitudinal axis of the fibers. It is particularly  
5 preferred that the filaments be of substantially circular, flat or oblong cross-section, most preferably the former.

By network is meant a plurality of fibers arranged into a predetermined configuration or a plurality of fibers grouped together to form a twisted or untwisted yarn, which yarns are arranged into a predetermined configuration. For  
10 example, the fibers or yarn may be formed as a felt or other nonwoven, knitted or woven (plain, basket, satin and crow foot weaves, etc.) into a network, or formed into a network by any conventional techniques. According to a particularly preferred network configuration, the fibers are unidirectionally aligned so that they are substantially parallel to each other along a common fiber direction. Continuous  
15 length fibers are most preferred although fibers that are oriented and have a length of from about 3 to 12 inches (about 7.6 to about 30.4 centimeters) are also acceptable and are deemed "substantially continuous" for purposes of this invention.

It is preferred that within a fibrous layer at least about 10 weight percent of  
20 the fibers, more preferably at least about 50 weight percent, and most preferably at least about 75 weight percent, be substantially continuous lengths of fiber that encircle the volume enclosed by the container. By encircle the volume is meant in the band or hoop direction, i.e., substantially parallel to or in the direction of the band, as band has been previously defined and shown. By substantially parallel to  
25 or in the direction of the band is meant within  $\pm 10^\circ$ . It is also preferred that the bands of the present invention be substantially seamless. By substantially seamless is meant that the band is seamless across each edge joining adjacent faces for more than at least one full wrap of the fibrous layer and also that at any given point on the band there is at least one wrap /layer that is seamless. With this definition, the  
30 band 12' of FIGURE 2A would be considered substantially seamless, even though its flaps X and Y are not joined to one another. Thus, each face of a band is

preferably connected to another face at at least one common edge with a fibrous material that functions as a hinge therebetween; the preferred fibrous material comprises substantially continuous, parallel lengths of fiber perpendicular to the edge.

- 5           The continuous bands can be fabricated using a number of procedures. In one preferred embodiment, the bands, especially those without resin matrix, are formed by winding fabric around a mandrel and securing the shape by suitable securing means, e.g., heat and/or pressure bonding, heat shrinking, adhesives, staples, sewing and other securing means known to those of skill in the art.
- 10   Sewing can be either spot sewing, line sewing or sewing with intersecting sets of parallel lines. Stitches are typically utilized in sewing, but no specific stitching type or method constitutes a preferred securing means for use in this invention. Fiber used to form stitches can also vary widely. Useful fiber may have a relatively low modulus or a relatively high modulus, and may have a relatively low tenacity or a
- 15   relatively high tenacity. Fiber for use in the stitches preferably has a tenacity equal to or greater than about 2 g/d and a modulus equal to or greater than about 20 g/d. All tensile properties are evaluated by pulling a 10 in (25.4 cm.) fiber length clamped between barrel clamps at 10 in/min (25.4 cm/min) on an Instron Tensile Tester. In cases where it is desirable to make the band somewhat more rigid,
- 20   pockets can be sewn in the fabric into which rigid plates may be inserted, or the plates themselves can be sewn into the band between wraps of material. This is another "collapsible" embodiment of rigid bands, i.e., the faces are rigid due to the presence of the rigid plates, but the edges are flexible due to the flexible fabric forming the bands or can be bent by, e.g., the weight of the rigid face portion. An
- 25   advantage to the collapsible embodiments of the present invention is that the apparatus can be transported flat and set up immediately prior to use. Another way to make wraps of fabric selectively rigid within a band is by way of stitch patterns, e.g., parallel rows of stitches can be used across the face portions of the band to make them rigid while leaving the joints/edges unsewn to create another
- 30   "collapsible" rigid band.

The type of fibers used in the blast resistant material may vary widely and can be inorganic or organic fibers. Preferred fibers for use in the practice of this invention, especially for the substantially continuous lengths, are those having a tenacity equal to or greater than about 10 grams/denier (g/d) and a tensile modulus  
5 equal to or greater than about 200 g/d (as measured by an Instron Tensile Testing machine). Particularly preferred fibers are those having a tenacity equal to or greater than about 20 g/d and a tensile modulus equal to or greater than about 500 g/d. Most preferred are those embodiments in which the tenacity of the fibers is equal to or greater than about 25 g/d and the tensile modulus is equal to or greater  
10 than about 1000 g/d. In the practice of this invention, the fibers of choice have a tenacity equal to or greater than about 30 g/d and a tensile modulus equal to or greater than about 1200 g/d.

High performance fibers can be incorporated into bands together and/or in conjunction with other fibers which may be inorganic, organic or metallic.  
15 Preferably the high performance fiber is the continuous (warp) fiber and the other fiber is the fill fiber. Optionally the other fiber can be incorporated in both warp and fill. Such fabrics are designated hybrid fabrics. Hybrid fabrics can be used to construct one or more bands of the container. Preferably, hybrid fabrics would be used to construct part or all of the outer band. Bands can also be created by  
20 simultaneously or serially wrapping one or more fabrics made with conventional fibers with one or more fabrics made from high performance fibers.

The denier of the fiber may vary widely. In general, fiber denier is equal to or less than about 8,000. In the preferred embodiments of the invention, fiber denier is from about 10 to about 4000, and in the more preferred embodiments of  
25 the invention, fiber denier is from about 10 to about 2000. In the most preferred embodiments of the invention, fiber denier is from about 10 to about 1500. Fabrics made with coarser (higher) denier fibers will allow more venting of gases, which may be desirable in some cases.

Useful inorganic fibers include S-glass fibers, E-glass fibers, carbon fibers,  
30 boron fibers, alumina fibers, zirconia-silica fibers, alumina-silica fibers and the like.

Illustrative of useful inorganic filaments for use in the present invention are glass fibers such as fibers formed from quartz, magnesia aluminosilicate, non-alkaline aluminoborosilicate, soda borosilicate, soda silicate, soda lime-aluminosilicate, lead silicate, non-alkaline lead boroalumina, non-alkaline barium boroalumina, non-alkaline zinc boroalumina, non-alkaline iron aluminosilicate, cadmium borate, alumina fibers which include "saffil" fiber in eta, delta, and theta phase form, asbestos, boron, silicone carbide, graphite and carbon such as those derived from the carbonization of saran, polyaramide (Nomex), nylon, polybenzimidazole, polyoxadiazole, polyphenylene, PPR, petroleum and coal pitches (isotropic), mesophase pitch, cellulose and polyacrylonitrile, ceramic fibers, metal fibers as for example steel, aluminum metal alloys, and the like.

Illustrative of useful organic filaments are those composed of polyesters, polyolefins, polyetheramides, fluoropolymers, polyethers, celluloses, phenolics, polyesteramides, polyurethanes, epoxies, aminoplastics, silicones, polysulfones, polyetherketones, polyetheretherketones, polyesterimides, polyphenylene sulfides, polyether acryl ketones, poly(amideimides), and polyimides. Illustrative of other useful organic filaments are those composed of aramids (aromatic polyamides), such as poly(m-xylylene adipamide), poly(p-xylylene sebacamide), poly(2,2,2-trimethyl-hexamethylene terephthalamide), poly(piperazine sebacamide), poly(metaphenylene isophthalamide) and poly(p-phenylene terephthalamide); aliphatic and cycloaliphatic polyamides, such as the copolyamide of 30% hexamethylene diammonium isophthalate and 70% hexamethylene diammonium adipate, the copolyamide of up to 30% bis-(-amidocyclohexyl)methylene, terephthalic acid and caprolactam, polyhexamethylene adipamide (nylon 66), poly(butyrolactam) (nylon 4), poly(9-aminononanoic acid) (nylon 9), poly(enantholactam) (nylon 7), poly(capryllactam) (nylon 8), polycaprolactam (nylon 6), poly(p-phenylene terephthalamide), polyhexamethylene sebacamide (nylon 6,10), polyaminoundecanamide (nylon 11), polydodecanolactam (nylon 12), polyhexamethylene isophthalamide, polyhexamethylene terephthalamide, polycaproamide, poly(nonamethylene azelamide (nylon 9,9), poly(decamethylene azelamide) (nylon 10,9), poly(decamethylene sebacamide) (nylon 10,10), poly[bis-

(4-aminocyclohexyl)methane 1,10-decanedicarboxamide] (Qiana) (trans), or combinations thereof; and aliphatic, cycloaliphatic and aromatic polyesters such as poly(1,4-cyclohexylidene dimethyl eneterephthalate) cis and trans, poly(ethylene-1,5-naphthalate), poly(ethylene-2,6-naphthalate), poly(1,4-cyclohexane

5 dimethylene terephthalate) (trans), poly(decamethylene terephthalate), poly(ethylene terephthalate), poly(ethylene isophthalate), poly(ethylene oxybenzoate), poly(para-hydroxy benzoate), poly(dimethylpropiolactone), poly(decamethylene adipate), poly(ethylene succinate), poly(ethylene azelate), poly(decamethylene sabacate), poly( $\alpha,\alpha$ -dimethylpropiolactone), and the like.

10 Also illustrative of useful organic filaments are those of liquid crystalline polymers such as lyotropic liquid crystalline polymers which include polypeptides such as poly- $\alpha$ -benzyl L-glutamate and the like; aromatic polyamides such as poly(1,4-benzamide), poly(chloro-1,4-phenylene terephthalamide), poly(1,4-phenylene fumaramide), poly(chloro-1,4-phenylene fumaramide), poly(4,4'-

15 benzanilide trans, trans-muconamide), poly(1,4-phenylene mesaconamide), poly(1,4-phenylene) (trans-1,4-cyclohexylene amide), poly(chloro-1,4-phenylene) (trans-1,4-cyclohexylene amide), poly(1,4-phenylene 1,4-dimethyl-trans-1,4-cyclohexylene amide), poly(1,4-phenylene 2,5-pyridine amide), poly(chloro-1,4-phenylene 2,5-pyridine amide), poly(3,3'-dimethyl-4,4'-biphenylene 2,5 pyridine

20 amide), poly(1,4-phenylene 4,4'-stilbene amide), poly(chloro-1,4-phenylene 4,4'-stilbene amide), poly(1,4-phenylene 4,4'-azobenzene amide), poly(4,4'-azobenzene 4,4'-azobenzene amide), poly(1,4-phenylene 4,4'-azoxybenzene amide), poly(4,4'-azobenzene 4,4'-azoxybenzene amide), poly(1,4-cyclohexylene 4,4'-azobenzene amide), poly(4,4'-azobenzene terephthal amide), poly(3,8-phenanthridinone

25 terephthal amide), poly(4,4'-biphenylene terephthal amide), poly(4,4'-biphenylene 4,4'-bibenzo amide), poly(1,4-phenylene 4,4'-bibenzo amide), poly(1,4-phenylene 4,4'-terephthylene amide), poly(1,4-phenylene 2,6-naphthal amide), poly(1,5-naphthalene terephthal amide), poly(3,3'-dimethyl-4,4'-biphenylene terephthal amide), poly(3,3'-dimethoxy-4,4'-biphenylene terephthal amide), poly(3,3'-

30 dimethoxy-4,4'-biphenylene 4,4'-bibenzo amide) and the like; polyoxamides such as those derived from 2,2'-dimethyl-4,4'-diamino biphenyl and chloro-1,4-phenylene

diamine; polyhydrazides such as poly chloroterephthalic hydrazide, 2,5-pyridine dicarboxylic acid hydrazide) poly(terephthalic hydrazide), poly(terephthalic-chloroterephthalic hydrazide) and the like; poly(amide-hydrazides) such as poly(terephthaloyl 1,4 amino-benzhydrazide) and those prepared from 4-amino-

5 benzhydrazide, oxalic dihydrazide, terephthalic dihydrazide and para-aromatic diacid chlorides; polyesters such as those of the compositions include poly(oxy-trans-1,4-cyclohexyleneoxycarbonyl-trans-1,4-cyclohexylenecarbonyl- $\beta$ -oxy-1,4-phenyl-eneoxyteraphthaloyl) and poly(oxy-cis-1,4-cyclohexyleneoxycarbonyl-trans-1,4-cyclohexylenecarbonyl- $\beta$ -oxy-1,4-phenyleneoxyterephthaloyl) in methylene

10 chloride-o-cresol poly(oxy-trans-1,4-cyclohexylene oxycarbonyl-trans-1,4-cyclohexylenecarbonyl-b-oxy-(2-methyl-1,4-phenylene)oxy-terephthaloyl) in 1,1,2,2-tetrachloroethane-o-chlorophenol-phenol (60:25:15 vol/vol/vol), poly[oxy-trans-1,4-cyclohexyleneoxycarbonyl-trans-1,4-cyclohexylenecarbonyl-b-oxy(2-methyl-1,3-phenylene)oxy-terephthaloyl] in o-chlorophenol and the like;

15 polyazomethines such as those prepared from 4,4'-diaminobenzanilide and terephthalaldehyde, methyl-1,4-phenylenediamine and terephthalaldehyde and the like; polyisocyanides such as poly(-phenyl ethyl isocyanide), poly(n-octyl isocyanide) and the like; polyisocyanates such as poly(n-alkyl isocyanates) as for example poly(n-butyl isocyanate), poly(n-hexyl isocyanate) and the like; lyotropic

20 crystalline polymers with heterocyclic units such as poly(1,4-phenylene-2,6-benzobisthiazole) (PBT), poly(1,4-phenylene-2,6-benzobisoxazole) (PEO), poly(1,4-phenylene-1,3,4-oxadiazole), poly(1,4-phenylene-2,6-benzobisimidazole), poly[2,5(6)-benzimidazole] (AB-PBI), poly[2,6-(1,4-phenylene-4-phenylquinoline], poly[1,1'-(4,4'-biphenylene)-6,6'-bis(4-phenylquinoline)] and the like;

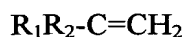
25 polyorganophosphazines such as polyphosphazine, polybisphenoxyphosphazine, poly[bis(2,2,2' trifluoroethylene) phosphazine] and the like; metal polymers such as those derived by condensation of trans-bis(tri-n-butylphosphine)platinum dichloride with a bisacetylene or trans-bis(tri-n-butylphosphine)bis(1,4-butadienyl)platinum and similar combinations in the presence of cuprous iodine and an amide; cellulose

30 and cellulose derivatives such as esters of cellulose as for example triacetate cellulose, acetate cellulose, acetate-butyrate cellulose, nitrate cellulose, and sulfate

cellulose, ethers of cellulose as for example, ethyl ether cellulose, hydroxymethyl ether cellulose, hydroxypropyl ether cellulose, carboxymethyl ether cellulose, ethyl hydroxyethyl ether cellulose, cyanoethylethyl ether cellulose, ether-esters of cellulose as for example acetoxyethyl ether cellulose and benzoyloxypropyl ether cellulose, and urethane cellulose as for example phenyl urethane cellulose;

thermotropic liquid crystalline polymers such as celluloses and their derivatives as for example hydroxypropyl cellulose, ethyl cellulose propionoxypropyl cellulose; thermotropic copolyesters as for example copolymers of 6-hydroxy-2-naphthoic acid and p-hydroxy benzoic acid, copolymers of 6-hydroxy-2-naphthoic acid, terephthalic acid and p-amino phenol, copolymers of 6-hydroxy-2-naphthoic acid, terephthalic acid and hydroquinone, copolymers of 6-hydroxy-2-naphthoic acid, p-hydroxy benzoic acid, hydroquinone and terephthalic acid, copolymers of 2,6-naphthalene dicarboxylic acid, terephthalic acid, isophthalic acid and hydroquinone, copolymers of 2,6-naphthalene dicarboxylic acid and terephthalic acid, copolymers of p-hydroxybenzoic acid, terephthalic acid and 4,4'-dihydroxydiphenyl, copolymers of p-hydroxybenzoic acid, terephthalic acid, isophthalic acid and 4,4'-dihydroxydiphenyl, p-hydroxybenzoic acid, isophthalic acid, hydroquinone and 4,4'-dihydroxybenzophenone, copolymers of phenylterephthalic acid and hydroquinone, copolymers of chlorohydroquinone, terephthalic acid and p-acetoxy cinnamic acid, copolymers of chlorohydroquinone, terephthalic acid and ethylene dioxy-r,r'-dibenzoic acid, copolymers of hydroquinone, methylhydroquinone, p-hydroxybenzoic acid and isophthalic acid, copolymers of (1-phenylethyl)hydroquinone, terephthalic acid and hydroquinone, and copolymers of poly(ethylene terephthalate) and p-hydroxybenzoic acid; and thermotropic polyamides and thermotropic copoly(amide-esters).

Also illustrative of useful organic filaments are those composed of extended chain polymers formed by polymerization of  $\alpha,\beta$ -unsaturated monomers of the formula:



wherein:



$R_1$  and  $R_2$  are the same or different and are hydrogen, hydroxy, halogen, alkylcarbonyl, carboxy, alkoxycarbonyl, heterocycle or alkyl or aryl either unsubstituted or substituted with one or more substituents selected from the group consisting of alkoxy, cyano, hydroxy, alkyl and aryl. Illustrative of such polymers of  $\alpha,\beta$ -unsaturated monomers are polymers including polystyrene, polyethylene, polypropylene, poly(1-octadecene), polyisobutylene, poly(1-pentene), poly(2-methylstyrene), poly(4-methylstyrene), poly(1-hexene), poly(4-methoxystyrene), poly(5-methyl-1-hexene), poly(4-methylpentene), poly(1-butene), polyvinyl chloride, polybutylene, polyacrylonitrile, poly(methyl pentene-1), poly(vinyl alcohol), poly(vinyl acetate), poly(vinyl butyral), poly(vinyl chloride), poly(vinylidene chloride), vinyl chloride-vinyl acetate chloride copolymer, poly(vinylidene fluoride), poly(methyl acrylate), poly(methyl methacrylate), poly(methacrylonitrile), poly(acrylamide), poly(vinyl fluoride), poly(vinyl formal), poly(3-methyl-1-butene), poly(4-methyl-1-butene), poly(4-methyl-1-pentene), poly(1-hexane), poly(5-methyl-1-hexene), poly(1-octadecene), poly(vinyl cyclopentane), poly(vinylcyclohexane), poly( $\alpha$ -vinyl naphthalene), poly(vinyl methyl ether), poly(vinylethylether), poly(vinyl propylether), poly(vinyl carbazole), poly(vinyl pyrrolidone), poly(2-chlorostyrene), poly(4-chlorostyrene), poly(vinyl formate), poly(vinyl butyl ether), poly(vinyl octyl ether), poly(vinyl methyl ketone), poly(methylisopropenyl ketone), poly(4-phenylstyrene) and the like.

The most useful high strength fibers include extended chain polyolefin fibers, particularly extended chain polyethylene (ECPE) fibers, aramid fibers, polyvinyl alcohol fibers, polyacrylonitrile fibers, liquid crystal copolyester fibers, polyamide fibers, glass fibers, carbon fibers and/or mixtures thereof. Particularly preferred are the polyolefin and aramid fibers. If a mixture of fibers is used, it is preferred that the fibers be a mixture of at least two of polyethylene fibers, aramid fibers, polyamide fibers, carbon fibers, and glass fibers.

U.S.P. 4,457,985 generally discusses such extended chain polyethylene and polypropylene fibers, and the disclosure of this patent is hereby incorporated by reference to the extent that it is not inconsistent herewith. In the case of polyethylene, suitable fibers are those of weight average molecular weight of at

least 150,000, preferably at least one million and more preferably between two million and five million. Such extended chain polyethylene fibers may be grown in solution as described in U.S.P. 4,137,394 or U.S.P. 4,356,138, or may be spun from a solution to form a gel structure, as described in German Off. 3,004,699 and  
5 GB 2051667, and especially as described in U.S.P. 4,413,110, 4,551,296, all of which are hereby incorporated by reference. As used herein, the term polyethylene shall mean a predominantly linear polyethylene material that may contain minor amounts of chain branching or comonomers not exceeding 5 modifying units per 100 main chain carbon atoms, and that may also contain admixed therewith not  
10 more than about 50 weight percent of one or more polymeric additives such as alkene-1-polymers, in particular low density polyethylene, polypropylene or polybutylene, copolymers containing mono-olefins as primary monomers, oxidized polyolefins, graft polyolefin copolymers and polyoxymethylenes, or low molecular weight additives such as antioxidants, lubricants, ultraviolet screening agents,  
15 colorants and the like which are commonly incorporated by reference. Depending upon the formation technique, the draw ratio and temperatures, and other conditions, a variety of properties can be imparted to these filaments. The tenacity of the filaments is at least about 15 g/d, preferably at least 20 g/d, more preferably at least 25 g/d and most preferably at least 30 g/d. Similarly, the tensile modulus of  
20 the filaments, as measured by an Instron tensile testing machine, is at least about 200 g/d, preferably at least 500 g/d, more preferably at least 1,000 g/d, and most preferably at least 1,200 g/d. These highest values for tensile modulus and tenacity are generally obtainable only by employing solution grown or gel filament processes. Many of the filaments have melting points higher than the melting point  
25 of the polymer from which they were formed. Thus, for example, high molecular weight polyethylene of 150,000, one million and two million generally have melting points in the bulk of 138°C. The highly oriented polyethylene filaments made of these materials have melting points of from about 7° to about 13°C higher. Thus, a slight increase in melting point reflects the crystalline perfection and higher  
30 crystalline orientation of the filaments as compared to the bulk polymer.

Similarly, highly oriented extended chain polypropylene fibers of weight average molecular weight at least 200,000, preferably at least one million and more preferably at least two million, may be used. Such extended chain polypropylene may be formed into reasonably well oriented filaments by techniques described in the various references referred to above, and especially by the technique of U.S.P.'s 4,413,110, 4,551,296, 4,663,101, and 4 784 820, hereby incorporated by reference. Since polypropylene is a much less crystalline material than polyethylene and contains pendant methyl groups, tenacity values achievable with polypropylene are generally substantially lower than the corresponding values for polyethylene.

Accordingly, a suitable tenacity is at least about 8 g/d, with a preferred tenacity being at least about 11 g/d. The tensile modulus for polypropylene is at least about 160 g/d, preferably at least about 200 g/d. The melting point of the polypropylene is generally raised several degrees by the orientation process, such that the polypropylene filament preferably has a main melting point of at least 168°C., more preferably at least 170°C. The particularly preferred ranges for the above-described parameters can be advantageously provide improved performance in the final article. Employing fibers having a weight average molecular weight of at least about 200,000 coupled with the preferred ranges for the above-described parameters (modulus and tenacity) can provide advantageously improved performance in the final article.

High molecular weight polyvinyl alcohol fibers having high tensile modulus are described in U.S.P. 4,440,711, which is hereby incorporated by reference to the extent it is not inconsistent herewith. High molecular weight PV-OH fibers should have a weight average molecular weight of at least about 200,000. Particularly useful PV-OH fibers should have a modulus of at least about 300 g/d, a tenacity of at least about 7 g/d (preferably at least about 10 g/d, more preferably about 14 g/d, and most preferably at least about 17 g/d), and an energy-to-break of at least about 8 joules/g. PV-OH fibers having a weight average molecular weight of at least about 200,000, a tenacity of at least about 10 g/d, a modulus of at least about 300 g/d, and an energy to break of about 8 joules/g are likely to be more useful in producing articles of the present invention. PV-OH fibers having such properties

can be produced, for example, by the process disclosed in U.S.P. 4,599,267, hereby incorporated by reference.

In the case of polyacrylonitrile (PAN), PAN fibers for use in the present invention are of molecular weight of at least about 400,000. Particularly useful  
5 PAN fiber should have a tenacity of at least about 10 g/d and an energy-to-break of at least about 8 joules/g. PAN fibers having a molecular weight of at least about 400,000, a tenacity of at least about 15 to about 20 g/d and an energy-to-break of at least about 8 joules/g are most useful; such fibers are disclosed, for example, in U.S.P. 4,535,027, hereby incorporated by reference.

10 In the case of aramid fibers, suitable aramid fibers formed principally from aromatic polyamide are described in U.S.P. 3,671,542, hereby incorporated by reference. Preferred aramid fiber will have a tenacity of at least about 20 g/d, a tensile modulus of at least about 400 g/d and an energy-to-break at least about 8 joules/g, and particularly preferred aramid fiber will have a tenacity of at least  
15 about 20 g/d, a modulus of at least about 480 g/d and an energy-to-break of at least about 20 joules/g. Most preferred aramid fibers will have a tenacity of at least about 20 g/d, a modulus of at least about 900 g/d and an energy-to-break of at least about 30 joules/g. For example, poly(phenylenediamine terephthalamide) filaments produced commercially by Dupont Corporation under the trade name of  
20 KEVLAR® 29, 49, 129 and 149 and having moderately high moduli and tenacity values are particularly useful in forming articles of the present invention. KEVLAR 29 has 500 g/d and 22 g/d and KEVLAR 49 has 1000 g/d and 22 g/d as values of modulus and tenacity, respectively. Also useful in the practice of this invention is poly(metaphenylene isophthalamide) fibers produced commercially by  
25 Dupont under the trade name NOMEX®.

In the case of liquid crystal copolyesters, suitable fibers are disclosed, for example, in U.S.P. No.'s 3,975,487; 4,118,372; and 4,161,470, hereby incorporated by reference. Tenacity's of about 15 to about 30 g/d and preferably about 20 to about 25 g/d, and tensile modulus of about 500 to 1500 g/d and  
30 preferably about 1000 to about 1200 g/d are particularly desirable.

If a matrix material is employed in the practice of this invention, it may comprise one or more thermosetting resins, or one or more thermoplastic resins, or a blend of such resins. The choice of a matrix material will depend on how the bands are to be formed and used. The desired rigidity of the band and/or ultimate  
5 container will greatly influence choice of matrix material. As used herein "thermoplastic resins" are resins which can be heated and softened, cooled and hardened a number of times without undergoing a basic alteration, and "thermosetting resins" are resins which cannot be resoftened and reworked after molding, extruding or casting and which attain new, irreversible properties when  
10 once set at a temperature which is critical to each resin.

The tensile modulus of the matrix material in the band(s) may be low (flexible) or high (rigid), depending upon how the band is to be used. The key requirement of the matrix material is that it be flexible enough to process at whatever stage of the band-forming method it is added. In this regard,  
15 thermosetting resins which are fully uncured or have been B-staged but not fully cured would probably process acceptably, as would fully cured thermosetting resins which can be plied together with compatible adhesives. Heat added to the process would permit processing of higher modulus thermoplastic materials which are too rigid to process otherwise; the temperature "seen" by the material and  
20 duration of exposure must be such that the material softens for processing without adversely affecting the impregnated fibers, if any.

With the foregoing in mind, thermosetting resins useful in the practice of this invention may include, by way of illustration, bismaleimides, alkyds, acrylics, amino resins, urethanes, unsaturated polyesters, silicones, epoxies, vinylesters and  
25 mixtures thereof. Greater detail on useful thermosetting resins may be found in U.S.P. 5,330,820, hereby incorporated by reference. Particularly preferred thermosetting resins are the epoxies, polyesters and vinylesters, with an epoxy being the thermosetting resin of choice.

Thermoplastic resins for use in the practice of this invention may also vary  
30 widely. Illustrative of useful thermoplastic resins are polylactones, polyurethanes, polycarbonates, polysulfones, polyether ether ketones, polyamides, polyesters,

poly(arylene oxides), poly(arylene sulfides), vinyl polymers, polyacrylics, polyacrylates, polyolefins, ionomers, polyepichlorohydrins, polyetherimides, liquid crystal resins, and elastomers and copolymers and mixtures thereof. Greater detail on useful thermoplastic resins may be found in U.S.P. 5,330,820, hereby  
5 incorporated by reference. Particularly preferred low modulus thermoplastic (elastomeric) resins are described in U.S.P. 4,820,568, hereby incorporated by reference, in columns 6 and 7, especially those produced commercially by the Shell Chemical Co. which are described in the bulletin "KRATON Thermoplastic Rubber", SC-68-81. Particularly preferred thermoplastic resins are the high  
10 density, low density, and linear low density polyethylenes, alone or as blends, as described in U.S.P. 4,820,458. A broad range of elastomers may be used, including natural rubber, styrene-butadiene copolymers, polyisoprene, polychloroprene-butadiene-acrylonitrile copolymers, ER rubbers, EPDM rubbers, and polybutylenes.

15 In the preferred embodiments of the invention, the matrix comprises a low modulus polymeric matrix selected from the group consisting of a low density polyethylene; a polyurethane; a flexible epoxy; a filled elastomer vulcanizate; a thermoplastic elastomer; and a modified nylon-6.

The proportion of matrix to filament in the bands is not critical and may  
20 vary widely. In general, the matrix material forms from about 10 to about 90% by volume of the fibers, preferably about 10 to 80%, and most preferably about 10 to 30%.

If a matrix resin is used, it may be applied in a variety of ways to the fiber, e.g., encapsulation, impregnation, lamination, extrusion coating, solution coating,  
25 solvent coating. Effective techniques for forming coated fibrous layers suitable for use in the present invention are detailed in referenced U.S.P.'s 4,820,568 and 4,916,000.

The blast resistant bands can be made according to the following method steps:

A. wrapping at least one flexible sheet comprising a high strength fiber material around a mandrel in a plurality of layers under tension sufficient to remove voids between successive layers;

5 B. securing the layers of material together to form a substantially seamless and at least partially rigid first band; and

C. removing the band from the mandrel.

The wrapping tension typically is in the range of from about 0.1 to 50 pounds per linear inch, more preferably in the range of from about 2 to 50 pounds per linear inch, most preferably in the range of from about 2 to 20 pounds per linear inch.

10 The fabric layers can be secured in a variety of ways, e.g., by heat and/or pressure bonding, heat shrinking, adhesives, staples, and sewing, as discussed above. It is most preferred that the securing step comprises the steps of contacting the fiber material with a resin matrix and consolidating the layers of high strength fiber material and the resin matrix either on or off of the mandrel. The fiber material can  
15 be contacted with a resin matrix either before, during or after the wrapping step.

Some of the ways in which this can be done are detailed further below. By “consolidating” is meant combining the matrix material and the fiber network into a single unitary layer. Depending upon the type of matrix material and how it is applied to the fibers, consolidation can occur via drying, cooling, pressure or a  
20 combination thereof, optionally in combination with application of an adhesive. “Consolidating” is also meant to encompass spot consolidation wherein the faces of a band are consolidated but the edges are not. In this fashion, the faces can be made rigid while the edges retain the ability to bend or be bent to permit collapsing or folding of the band. “Sheet” is meant to include a single fiber or roving for  
25 purposes of this invention.

Another method of making bands for assembly into a blast resistant container comprises the steps of:

A. wrapping a first flexible sheet of a high strength fiber material around a mandrel in a plurality of layers under sufficient tension to remove voids between  
30 successive layers to form a first band;

B. contacting the high strength fiber material of the first flexible sheet with a resin matrix;

C. placing spacing means on the exterior of the first band;

D. wrapping a second flexible sheet of a high strength fiber material  
5 around the spacing means in a plurality of layers under sufficient tension to remove voids between successive layers to form a second band;

E. contacting the high strength fiber material of the second flexible sheet with a resin matrix;

F. placing second spacing means on the exterior of the second band;

10 G. wrapping a third flexible sheet of a high strength fiber material around the second spacing means in a plurality of layers under sufficient tension to remove voids between successive layers to form a third band;

H. contacting the high strength fiber of the third flexible sheet with a resin matrix;

15 I. repeating the placing, wrapping, and contacting steps to create a desired number of bands;

J. consolidating at least a part of each of the bands on the mandrel; and

K. removing the bands and spacing means from the mandrel.

This method allows formation of all of the bands for a single container at one time.

20 In one preferred embodiment, the flexible sheet material is formed as follows. Yarn bundles of from about 30 to about 2000 individual filaments of less than about 12 denier, and more preferably of about 100 individual filaments of less than about 7 denier, are supplied from a creel, and are led through guides and a spreader bar into a collimating comb just prior to coating. The collimating comb  
25 aligns the filaments coplanarly and in a substantially parallel, and unidirectional fashion. The filaments are then sandwiched between release papers, one of which is coated with a wet matrix resin. This system is then passed under a series of pressure rolls to complete the impregnation of the filaments. The top release paper is pulled off and rolled up on a take-up reel while the impregnated network of  
30 filaments proceeds through a heated tunnel oven to remove solvent and then be taken up. Alternatively, a single release paper coated with the wet matrix resin can



be used to create the impregnated network of filaments. One such impregnated network is referred to as unidirectional prepreg, tape or sheet material and is one of the preferred feed materials for making some of the bands in the examples below.

In an alternate embodiment of this invention, two such impregnated  
5 networks are continuously cross plied, preferably by cutting one of the networks into lengths that can be placed successively across the width of the other network in a 0°/90° orientation. This forms a continuous flexible sheet of high strength fiber material. See U.S.P. 5,173,138, hereby incorporated by reference. This flexible sheet (fibrous layer), optionally with film as discussed below, can then be  
10 used to form one or more bands in accordance with the methods of the present invention. This fibrous layer is sufficiently flexible to wrap in accordance with the methods of the present invention; it can then be made substantially rigid (per the drapability test), if desired, either by the sheer number of wraps or by the manner in which it is secured. The weight percent of fiber in the hoop direction of the band  
15 can be varied by varying the number and the orientation of the networks. One way to achieve varying weight percents of fiber in the hoop direction is to make a composite sheet from the cross plied material and one or more layers of unidirectional tape/material (see the examples which follow). By way of example, two unidirectional sheets with one cross-ply sheet forms an imbalanced fabric  
20 having about 75 weight percent fiber in the hoop direction.

In another embodiment, one or more uncured thermosetting resin-impregnated networks of high strength filaments are similarly formed into a flexible sheet for winding around a mandrel into a band or bands in accordance with the present invention followed by curing (or spot curing) of the resin.

25 Film may optionally be used as one or more layers of the band(s), preferably as an outer layer. The film, or films, can be added as the matrix material (lamination), with the matrix material or after the matrix material, as the case may be. When the film is added as the matrix material, it is preferably simultaneously wound with the fiber or fabric (network) onto a mandrel and subsequently  
30 consolidated; the mandrel may optionally become part of the structure. The film thickness minimally is about 0.1 mil and may be as large as desired so long as the

length is still sufficiently flexible to permit band formation. The preferred film thickness ranges from 0.1 to 50 mil, with 0.35 to 10 mil being most preferred. Films can also be used on the surfaces of the bands for a variety of reasons, e.g., to vary frictional properties, to increase flame retardance, to increase chemical  
5 resistance, to increase resistance to radiation degradation, and/or to prevent diffusion of material into the matrix. The film may or may not adhere to the band depending on the choice of film, resin and filament. Heat and/or pressure may cause the desired adherence, or it may be necessary to use an adhesive which is heat or pressure sensitive between the film and the band to cause the desired  
10 adherence. Examples of acceptable adhesives include polystyrene-polyisoprene-polystyrene block copolymer, thermoplastic elastomers, thermoplastic and thermosetting polyurethanes, thermoplastic and thermosetting polysulfides, and typical hot melt adhesives.

Films which may be used as matrix materials in the present invention  
15 include thermoplastic polyolefinic films, thermoplastic elastomeric films, crosslinked thermoplastic films, crosslinked elastomeric films, polyester films, polyamide films, fluorocarbon films, urethane films, polyvinylidene chloride films, polyvinyl chloride films and multilayer films. Homopolymers or copolymers of these films can be used, and the films may be unoriented, uniaxially oriented or  
20 biaxially oriented. The films may include pigments or plasticizers.

Useful thermoplastic polyolefinic films include those of low density polyethylene, high density polyethylene, linear low density polyethylene, polybutylene, and copolymers of ethylene and propylene which are crystalline. Polyester films which may be used include those of polyethylene terephthalate and  
25 polybutylene terephthalate.

Pressure can be applied by an interleaf material made from a plastic film wrap which shrinks when the band is exposed to heat; acceptable materials for this application, by way of example, are polyethylene, polyvinyl chloride and ethylene-vinylacetate copolymers.

30 The temperatures and/or pressures to which the bands of the present invention are exposed to cure the thermosetting resin or to cause adherence of the

networks to each other and optionally, to at least one sheet of film, vary depending upon the particular system used. For example, for extended chain polyethylene filaments, temperatures range from about 20°C. to about 150°C., preferably from about 50°C. to about 145°C., more preferably from about 80°C. to about 120°C, depending on the type of matrix material selected. The pressures may range from about 10 psi (69 kPa) to about 10,000 psi (69,000 kPa). A pressure between about 10 psi (69 kPa) and about 500 psi (3450 kPa), when combined with temperatures below about 100°C. for a period of time less than about 1.0 min., may be used simply to cause adjacent filaments to stick together. Pressures from about 100 psi (690 kPa) to about 10,000 psi (69,000 kPa), when coupled with temperatures in the range of about 100°C. to about 155°C. for a time of between about 1 to about 5 min., may cause the filaments to deform and to compress together (generally in a film-like shape). Pressures from about 100 psi (690 kPa) to about 10,000 psi (69,000 kPa), when coupled with temperatures in the range of about 150°C. to about 155°C for a time of between 1 to 5 min., may cause the film to become translucent or transparent. For polypropylene filaments, the upper limitation of the temperature range would be about 10 to about 20°C. higher than for ECPE filament. For aramid filaments, especially Kevlar filaments, the temperature range would be about 149 to 205°C. (about 300 to 400°F.).

Pressure may be applied to the bands on the mandrel in a variety of ways. Shrink wrapping with plastic film wrap is mentioned above. Autoclaving is another way of applying pressure, in this case simultaneous with the application of heat. The exterior of each band may be wrapped with a shrink wrappable material and then exposed to temperatures which will shrink wrap the material and thus apply pressure to the band. The band can be shrink wrapped on the mandrel in its hoop direction which will consolidate the entire band, or the band can be shrink wrapped across its faces with material placed around the band wrapped mandrel perpendicular to the hoop direction of the band; in the latter case, the edges of the band can remain unconsolidated while the faces are consolidated.

Many of the bands formed with fibrous layers utilizing elastomeric resin systems, thermosetting resin systems, or resin systems wherein a thermoplastic

resin is combined with an elastomeric or thermosetting resin can be treated with pressure alone to consolidate the band. This is the preferred way of consolidating the band. However, many of the bands formed with continuous lengths/plies utilizing thermoplastic resin systems can be treated with heat, alone or combined  
5 with pressure, to consolidate the band.

In the most preferred embodiments, each fibrous layer has an areal density of from about 0.1 to about 0.15 kg/m<sup>2</sup>. The areal density per band ranges from about 1 to about 40 kg/m<sup>2</sup>, preferably from about 2 to 20 kg/m<sup>2</sup>, and more preferably from about 4 to about 10 kg/m<sup>2</sup>. In the embodiment where SPECTRA  
10 SHIELD® composite nonwoven fabric forms a fibrous layer, these areal densities correspond to a number of fibrous layers per band ranging from about 10 to about 400, preferably from about 20 to about 200, more preferably from about 40 to about 100. In the three band cube design of the most preferred embodiment of the present invention, each face of the cube comprises two bands of blast resistant  
15 material, which effectively doubles the aforesaid ranges for each face of the cube. Where fibers other than high strength extended chain polyethylene, like SPECTRA® polyethylene fibers, are utilized the number of layers may need to be increased to achieve the high strength and modulus characteristics provided by the preferred embodiments.

20 By blast mitigating material is meant any material that functionally improves the resistance of the container to blast. The preferred blast mitigating material utilized in forming the container assemblies of the present invention are polymeric foams; particulates, such as vermiculite; condensable gases, preferably non-flammable; heat sink materials; foamed glass; microballoons; balloons; bladders;  
25 hollow spheres, preferably elastomeric such as basketballs and tennis balls; wicking fibers; and combinations thereof. These materials are used to surround the explosive or explosive-carrying luggage within the blast resistant container, and mitigate the shock wave transmitted by an explosion.

Chemical explosions are characterized by a rapid self-propagating  
30 decomposition which liberates considerable heat and develops a sudden pressure effect through the action of heat on the produced or adjacent gases. On a weight

basis, the heat of vaporization of water is similar to the heat liberated by the explosive. Provided that rapid heat transfer can be accomplished, water has the potential of greatly decreasing the blast overpressure. One technique to achieve the desired effect is to surround the explosive with heat sink materials. Effective

5 heat sink materials include aqueous foams; aqueous solutions having antifreeze therein such as glycerin, ethylene glycol; hydrated inorganic salts; aqueous gels, preferably reinforced; aqueous mists; wet sponges, preferably elastomeric; wet profiled fibers; wet fabrics; wet felts; and combinations thereof. Aqueous foams are most preferred, especially aqueous foams having a density in the range of from

10 about 0.01 to about 0.10 g/cm<sup>3</sup>, more preferably in the range of from about 0.03 to about 0.08 g/cm<sup>3</sup>.

In general, aqueous foams, through a number of mechanisms, transform energy of the explosion to heat energy within the aqueous phase. After an explosion venting of gases occurs in most containers, and when the pressure drops

15 below some critical value the collapsed foam expands again causing additional slow release of gases. The presence of these foams decreases the rate at which energy is transmitted from the container to the surroundings, and thereby decreases the hazard. Aqueous foams for use with this invention are preferably prepared with gases (foaming agents) which do not support combustion and that are condensable.

20 By condensable is meant that under pressure the gas will change phase from gas to liquid, simultaneously evolving their heat of condensation which heats the aqueous solution with which the gas has intimate contact. The gas selected for a particular application will depend on ambient temperature and on the pressure that the container (within which the gas is placed) can withstand. Preferred gases include

25 the hydrocarbons such as propane, butane (both isomers), and pentane(all isomers); carbon dioxide; inorganic gases such as ammonia, sulfur dioxide; fluorocarbons, particularly the hydrochlorofluorocarbons and the hydrofluorocarbons, such as, for example, the GENETRON® series of refrigerants commercially available from AlliedSignal Inc. as set forth in the AlliedSignal GENETRON® Products

30 Brochure, published January, 1995, and hereby incorporated by reference; and combinations thereof. A preferred gas is isobutane, which can be condensed at

modest pressures, about 30 psi at room temperature. Mixtures of condensable and non-condensable gases can be used. For example, a mixture of isobutane and tetrafluoromethane can be used for a room temperature application. The blast overpressure would cause the isobutane to condense but the tetrafluoromethane would remain gaseous. Preferred gases have low sonic velocities.

In order to rapidly dispense aqueous foams, it may be desirable to use a gas that does not condense in the pressurized canister, in combination with a condensed gas. Carbon dioxide, nitrogen, nitrous oxide or carbon tetrafluoride could serve as such as gas. Gases which vaporize to provide propellant action cool the canister during dispensing and the rate of discharge slows.

Considerations which are used for selection of foaming agent for an aqueous foam can also be used in selection of condensable gases to be used as the blast mitigating material in collapsible containers (in the absence of aqueous foam). Such gases can conveniently be confined in bladders within the containers.

The following examples are presented to provide a more complete understanding of the invention and are not to be construed as limitations thereon. In the examples, the following technical terms are used:

(a) "Areal Density" is the weight of a structure per unit area of the structure in  $\text{kg/m}^2$ . Panel areal density is determined by dividing the weight of the panel by the area of the panel. For a band having a polygonal cross-sectional area, areal density of each face is given by the weight of the face divided by the surface area of the face. In most cases, the areal density of all faces is the same, and one can refer to the areal density of the structure. However in some cases the areal density of the different faces is different. For a band having a circular cross-sectional area, areal density is determined by dividing the weight of the band by the exterior surface area of the band. For a cubic box container, the areal density is the areal density of each of the six panels forming the faces of the box and does not include the areal density of any hinges or pins.

(B) "Fiber Areal Density of a Composite" corresponds to the weight of the fiber reinforcement per unit area of the composite.

(c) " $C_{50}$ ", a measure of blast resistance, is measured as the level of charge (in ounces) that will rupture the container/tube 50 % of the time (where  $C_0$  represents no failures/ruptures and  $C_{100}$  represents failure 100% of the time). If failure occurs at one level and not at the next lower level, the  $C_{50}$  is calculated by averaging the two levels.

In Examples 1 - 9 and 18, unless otherwise indicated, the explosive used was TRENCHRITE 5, a product of Explosives Technologies International and a class A explosive having a shock wave velocity of 5,900 m/sec (6,700 ft/sec). In Examples 10 - 17, unless otherwise indicated, the explosive used was C4, which is 90 percent RDX (cyclo-1,3,5-trimethylene-2,4,6-trinitroamine) and 10 percent of a plasticizer (polyisobutylene), a product of Hitech Inc., and a class A explosive having a shock wave velocity of 8200 m/sec (26,900 ft/sec). Also, for the boxes and tubes where high speed video results are reported, the video camera utilized to record the explosive events was a vhs video, Sylvania Model VCC159 AV01. The camera was remotely operated and was located so that the subject box or tube filled approximately 30% of the viewing area.

The specific techniques, conditions, materials, proportions and reported data set forth to illustrate the principles of the invention are exemplary and should not be construed as limiting the scope of the invention.

#### EXAMPLE 1 (COMPARATIVE)

Three cubic boxes were constructed for testing, two utilizing SPECTRA SHIELD® composite panels for their faces and one utilizing KEVLAR® composite panels for its faces.

The box made from SPECTRA SHIELD composite was constructed (31 inches on a side) utilizing six flat SPECTRA SHIELD® composite panels as its faces, each 27 inches square, hinged together with two sets of hinges and two pins per edge (total of 24 pins and hinges). The panels, having an overall areal density of 1.14 lb/ft<sup>2</sup>, were constructed in the following manner.

Fabric shapes were partially wrapped around the perimeter rods of an aluminum frame. The wrapping (bending) occurred along a dotted line having an overall length of 27.25". Three fabric layers (shapes) were wrapped on each of the

four perimeter rods. These fabric shapes consisted of SPECTRA 1000 fabric, Style 904 (plain weave, 34 x 34 ends per inch, 650 denier SPECTRA 1000 yarn weighing 6 oz/yd<sup>2</sup>). The fabrics were impregnated with a sufficient amount of Dow XU71943.00L experimental vinyl ester resin (diallyl phthalate - 6 wt. %, methyl ethyl ketone - 31 wt. %, and vinyl ester resin - 63 wt. %) to produce an impregnated fabric having 80 wt. % SPECTRA 1000 and 20 wt. % resin. In all cases the resin contained 1.0 wt. % Lupersol 256, a product of the Lucidol Division of Ato Chem Corporation [2,5-dimethyl-2,5-bis(2-ethylhexanoylperoxy)hexane].

10       The aluminum frame was also used to wrap the square composite panels. Two rolls and of unidirectional prepreg tape were positioned to adjacent sides of the frame for wrapping alternatively around the frame to achieve a 0°/90°/0°/90°/etc. laydown of prepreg. The process was repeated until the desired areal density was attained. Each prepreg tape contained 7.6 ends per linear inch of 1500 denier SPECTRA 1000 yarn in Dow Resin XU71943.00L experimental vinyl ester resin, described above. The methyl ethyl ketone volatizes before the composite is cured. The prepreg was 76 wt. % SPECTRA 1000 fiber and 24 wt. % resin.

20       After wrapping was complete, the diagonal bar of the aluminum frame was removed, and the central area (27 x 27 inches) was molded at 120°C for 30 minutes under a force of 150 tons. The perimeter aluminum rods 126 were then removed, which left perimeter loops. The perimeter loops were then cut at intervals of 3 inches.

25       The cubic box container was assembled with one inch diameter cold rolled steel pins. One half of the perimeter loops were folded to be on the outside of the container and one half of the perimeter loops were folded to be on the inside of the container. There were 9 loops per edge, alternated inside and outside. Pins were placed in both the inside and outside loops, two per edge.

30       The box made from KEVLAR composite was constructed in a similar manner, except that KEVLAR 29 fabric (Style 423 - 2X2 basket weave of 1500 denier yarn, 14 oz/yd<sup>2</sup>) was utilized, and only one layer of the fabric was wrapped



around each perimeter rod. The panel overall areal density was the same as the SPECTRA SHIELD panel, i.e., 1.14 lb/ft<sup>2</sup>.

The first two boxes made from SPECTRA SHIELD composite panels were tested using 8 and 16 ounces of explosive charges, respectively, placed at their  
5 respective geometric centers. The box was found to withstand the blast from the 8 ounce explosion; however, considerable rapid venting occurred at the edges and corners of the box. The 16 ounce charge blew the container apart, and the steel hinge pins became dangerous projectiles.

The third box made from KEVLAR composite panels was tested using an 8  
10 ounce explosive charge placed at its geometric center. The explosion caused massive rupture of the container, and the steel hinge pins became dangerous projectiles.

## EXAMPLE 2

A SPECTRA SHIELD® PCR composite roll, commercially available from  
15 AlliedSignal, Inc., was cut into four 15 inch wide strips, each approximately 330 inches in length. The SPECTRA SHIELD® PCR composite contained 80 weight percent SPECTRA® 1000 extended chain polyethylene fiber (nominal tenacity of about 35 g/d, tensile modulus of about 1150 g/d, and elongation-to-break of about 3.4%, also available from AlliedSignal, Inc.) in a 20 weight percent resin matrix of  
20 polystyrene-polyisoprene-polystyrene block copolymer, available from Shell Co. under the trade name KRATON® D1107. The SPECTRA fibers were arranged in the composite in a 0°/90° configuration. Each strip was wrapped in successive layers around a square cross-sectional mandrel having a side length of 15 inches to form a band having 22 wraps of SPECTRA SHIELD. The wrapping of each  
25 successive strip was started at the point where the prior strip ended, with the identical fiber configuration and under sufficient tension (about 1 lb per linear inch) to minimize voids in successive wraps. An adhesive solution consisting of 5 g of KRATON D1107 per 95 g of toluene was painted onto the exterior of the strips during wrapping to provide adhesive material between successive wraps. A  
30 conventional rolling pin was used to consolidate the successive wraps during band formation to minimize voids in successive wraps.

After the first band had been completed, four 15 inch x 20 inch aluminum plates, each 0.125 inch thick and wrapped in TEFLON®-coated glass fabric, were affixed to the exterior of the band, one plate per face of the band, with the 15 inch side corresponding to the 15 inch side length of the mandrel. Masking tape was wrapped around the four aluminum plates to hold them in place, with a central area left without tape for wrapping the second band. A second band was formed by wrapping SPECTRA SHIELD PCR composite strips in a manner identical to that used for the first band. A second set of four aluminum plates were affixed to the faces of the second band followed by construction of a third band in the same manner as the first and second bands. The three bands were removed from the mandrel, and the toluene evaporated from the bands. In each band, 50 weight percent of the fiber was continuous and oriented in the hoop direction of the band.

The three bands were nested together as shown in FIGURE 1F to create a Box 1 for evaluation against an explosive charge. Each side of the box corresponds to 44 wraps of 0°/90° SPECTRA SHIELD PCR since there are faces of two bands covering each side of the box, and each band face comprises 22 wraps. The areal density of Box 1 =  $0.13 \times 44 = 5.72 \text{ kg/m}^2$  or  $1.17 \text{ lb/ft}^2$ . The weight of the Box 1 was 5.8 kg (12.6 lb).

Box 2 was constructed in the same manner as Box 1 with the following modifications. The first two strips of SPECTRA SHIELD composite used in constructing the first band were 24 inches wide. After removal of the band and evaporation of the toluene, the first band was cut into a distance of 4.5 inches from either side at each corner to allow for eight flaps (four on each side of the 15 inch wide band, two per face) of 4.5 inch width to be created. The flaps were made by folding the cut portion of the strip along the band width line. The plane of each flap was perpendicular to the plane of the side of the band to which it was attached. These flaps were held in place by the second and third bands. Weight of Box 2 was 6.08 kg (13.4 lb). The areal density of the faces was identical to Box 1, and the increase in weight was due to the flaps.

Boxes 3 and 4 were prepared in an identical manner to Box 2, and were essentially identical in weight and areal density.

Box 1 was tested using a 16 ounce explosive charge at its geometric center. During detonation, the edges of all three bands were completely or almost completely destroyed to result in a number of 15 inch square pieces, which were still intact and showed little damage.

5           Box 2 was tested using an 8 ounce charge in a manner identical to testing of Box 1. High speed video showed initial charge containment followed by distortion and breakage of band 3 at two opposite edges (broken band 3 consisted of two identical halves). Extensive gas venting occurred. Bands 1 and 2 remained essentially intact.

10           Box 3 was tested using a 2 ounce charge in a manner identical to testing of Box 1. High speed video showed minor gas venting during the detonation and bulging of the sides. However, the box remained intact. All three bands were undamaged.

            Box 4 was tested using a 4 ounce charge. High speed video showed more  
15   extensive venting and distortion of band 1 compared with Box 3. All three bands remained intact with no significant breakage.

### EXAMPLE 3

            A box was constructed in the same manner as Box 2 of Example 2 above, with the following changes. The mandrel was modified so that the edges were  
20   round, having a radius of 5/8 inch. The areal density of the bands was one-half that of Box 2. The flap width on Band 1, the inner band, was increased to 6 inches. Band was reinforced to control deformation and the rate of escape of gases from the explosion. This reinforcement consisted of first wrapping the mandrel in two complete wraps of 15 inch wide S-2 glass cloth (Style 6781, areal density 0.309  
25   kg/m<sup>2</sup>, manufactured by Clark Schwebel). This glass cloth was impregnated with EPON 828 epoxy resin, commercially available from the Shell Co., by using 8 pph Millamine, a cycloaliphatic diamine, available from Milliken Chemical Co., as a room temperature curing agent. The glass/resin ratio was 48/52 by weight. The SPECTRA SHIELD composite strips for Band 1 were then wound on top of the  
30   glass fabric, which became an integral part of Band 1.

To provide additional reinforcement, a panel of glass/epoxy composite, commercially available from 3M Corporation as Scotch Ply Type 1002 , was attached to each of the four inside surfaces of the glass fabric band (Band 1). Each panel measured about 13.5 x 14.5 inches, weighed 340 g and was 56 mil thick.

5 The panels were attached with a total of 200 g of a polysulfide adhesive PROSEAL 890-B1/2, manufactured by Courtaulds Aerospace Company. The inside surfaces of the 8 flaps were also reinforced by attaching to each a 3.75 x 13.75 inches piece of the glass/epoxy panel using Scotch 410 Flat Stock linear double coated paper tape, available from 3M Corporation. The total weight of

10 these 8 pieces of panel was 707 g. The assembled box weighed 6.17 kg (13.6 lb), consisting of 3.04 kg (6.7 lb) SPECTRA SHIELD composite and 3.13 kg (6.9 lb) fiber glass composite and adhesives.

This box was tested using a 6 ounce charge of TRENCHRITE 5 in a manner identical to testing of Boxes in Example 2. The container contained the

15 charge with minimum distortion, no rapid venting and essentially no visible permanent damage to the structure.

#### EXAMPLE 4

A box was constructed like Box 2 of Example 2 with the following modifications. In Band 1, the first half of the composite strip length was 21 inches

20 wide while the second half was 15 inches wide. This permitted eight flaps to be created, four per side of the band, each 3 inches by 15 inches and having an areal density  $4.75 \text{ kg/m}^2$ . Band 1 consisted of 70 SPECTRA SHIELD composite wraps and had an areal density of  $9.5 \text{ kg/m}^2$ . An 0.125 inch wide aluminum plate was placed around Band 1. Band 2 was formed by wrapping strips that were 17 inches

25 wide around the spacer. A second spacer of 0.125 inch width was placed around Band 2 and Band 3 was formed by wrapping strips that were 18 inches wide. The three bands were removed from the mandrel and from the spacers. In each band, about 50 weight percent of the fiber was continuous and oriented in the hoop direction.

30 Four 14 inch square fiberglass plates, commercially available from 3M Corporation as Scotch Ply Type 1002, and having an areal density of  $2.7 \text{ kg/m}^2$ ,

were glued to the inside faces of Band 1 using a total of about 128 g (32 g/face) of a polysulfide adhesive PROSEAL 890-B1/2, manufactured by Courtaulds Aerospace Company.

5 The three bands were assembled with Band 1 nesting inside of Band 2 which nested inside of Band 3, with two band faces per side. The flaps of Band 1 were held in place by Bands 2 and 3. The completed container had a side length of approximately 18 inches and weighed 24.06 kg (53 lb).

10 An M67 fragmentation hand grenade was modified so that it could be detonated electronically. The M67 grenade weighed 14 ounces and incorporated 6.5 ounces of compound B explosive. For greater detail on this standard hand grenade, reference may be had to Guide Book for Marines, 15th Revised Edition, Quantico, Virginia, p. 352, 09/01/86, hereby incorporated by reference. The grenade was placed in the geometrical center of the container and detonated. The container maintained its shape and the integrity of the individual bands. The  
15 container was disassembled and examined. The number of perforations in the four inner fiberglass panels of Band 1 indicated that more than 1200 steel projectiles were generated by the exploding grenade. Examination of the outer faces of the container indicated that 21 penetrations occurred.

20 The results of this test demonstrated that the basic containment concept was sound and can protect against a combination of projectiles and blast.

### EXAMPLE 5

A series of four identical tubes, 27 inches long and open at both ends, was prepared by wrapping SPECTRA SHIELD PCR composite around the mandrel having rounded edges described in Example 3. These tubes were substantially  
25 square in cross-section, and had a side length of 15 inches. The strip was 27 inches wide and a sufficient number of wraps were made to create a tube with a wall areal density of  $2.86 \text{ kg/m}^2$  ( $0.585 \text{ lb/ft}^2$ ). The areal density of the individual tubes is identical to the areal density of the individual bands for Boxes 1-4 of Example 2. With this construction, about 50 weight % of the fibers are continuous lengths in  
30 the hoop or band direction, i.e., encircling the tube. In all other respects, the

construction of the tube was identical to wrapping of the first band for Box 1 in Example 2.

These tubes were evaluated as follows. A charge was placed at the geometric center of each of the four tubes, A, B, C, and D, and electronically  
5 detonated. The weight of the charge was varied, as reported in Table 1, where results are set forth. An estimate of the  $C_{50}$  value for the tube design is set forth in Table 2.

#### EXAMPLE 6

A second series of four identical tubes was prepared as in Example 5,  
10 except that two layers of continuous unidirectional tape were affixed to either side of the conventional  $0^\circ/90^\circ$  SPECTRA SHIELD PCR composite strip to create a composite strip having a  $0^\circ/0^\circ/90^\circ/0^\circ$  fiber configuration with the  $0^\circ$  designation indicating continuous fiber lengths in the hoop or band direction. The continuous unidirectional tape was identical to tape that was cross-plyed to construct the  
15 conventional SPECTRA SHIELD PCR, as described in greater detail in Example 2. With this configuration, about 75 weight % of the fibers are continuous length fibers in the hoop or band direction, i.e., encircling the tube. All other parameters were identical to Example 5.

These tubes were tested in the same fashion as those of Example 5. Data is  
20 set forth in Table 1 and an estimate of  $C_{50}$  is set forth in Table 2.

#### EXAMPLE 7

A third series of four identical tubes was prepared as in Example 5 except these tubes were circular in cross-sectional area due to wrapping of the composite  
25 strip about a round mandrel 16.375 inches in diameter. The cross-sectional area of these tubes was identical to that of the tubes in Examples 5 and 6. About 50 weight % of the fibers are continuous length fibers in the hoop or band direction, i.e., encircling the tube.

These tubes were tested in the same fashion as those of Example 5. Data is  
30 set forth in Table 1 and an estimate of  $C_{50}$  is set forth in Table 2.

### EXAMPLE 8

Four more series of four identical tubes each were prepared for testing. In all of the series the tubes were substantially square in cross-section, had a side length of 7.5 inches, and were open at both ends.

5           In the first and second series, the tubes had overall tube lengths of 15 and 22.5 inches, respectively, and were prepared in the following manner. SPECTRA SHIELD PCR composite strip of the specified width (15 or 22.5 inches) was wrapped around the mandrel having rounded edges described in Example 3. A sufficient number of wraps were made to create a tube with a wall areal density of  
10   2.86 kg/m<sup>2</sup>. In all other respects, the construction of the tube was identical to wrapping of the band for Box 1 in Example 2, i.e., the KRATON adhesive solution was utilized and the successive wraps were consolidated.

          In the third and fourth series, the tubes had overall tube lengths of 15 and 22.5 inches, respectively, and were prepared in the following manner. SPECTRA  
15   SHIELD PCR composite strip of the specified width (15 or 22.5 inches) was wrapped around the mandrel having rounded edges described in Example 3. A sufficient number of wraps were made to create a tube having a wall areal density of 2.86 kg/m<sup>2</sup>. No adhesive was used although the success wraps were consolidated using a conventional rolling pin. The wrapped band/tube was placed  
20   between the platens of a hydraulic press under low pressure and molded at 120°C for 15 minutes. Since the edges of the mandrel were rounded, the SPECTRA SHIELD layers were not fully consolidated along the edges.

          These tubes were evaluated as follows. A charge was placed at the geometric center of each of the tubes and electronically detonated. The initial  
25   explosive charge evaluated was 1.5 ounces, which all of the four different tube types withstood. With an explosive charge of 2 ounces, however, all of the four different tube types ruptured. The calculated C<sub>50</sub> for the four different tube constructions, therefore, is 1.75 ounces. Data is set forth in Table 3.

**EXAMPLE 9**

Tubes identical to those described in Example 6 are constructed. In addition, five one-inch wide bands of unidirectional SPECTRA prepreg (identical to the unidirectional prepreg added to the 0°/90° SPECTRA SHIELD PCR in

5 Example 6) are wound in the hoop direction at 4 inch intervals on each tube. Either adhesives or heat and pressure may be used to consolidate the unidirectional bands, preferably the latter. Temperature of about 120°C. and pressure of about 5 psi for about 30 minutes is suitable. The areal density of these bands is 50% of the areal density of the tube. Because they cover 20% of the tube area, these bands

10 will add 10% to the weight of the tube. When these tubes are evaluated in a manner comparable to the tubes of Examples 5 and 6, it is anticipated that the bands will limit the length of tears to 4 inches and will control the rate of gas loss through such tears.

15

**EXAMPLE 10**

In this example, two identical cubic boxes A and B were constructed for testing, as follows.

A 27 inch wide sheet of SPECTRA SHIELD® PCR composite material, areal density 0.135 kg/m<sup>2</sup>, was wrapped in 18 successive layers around a square

20 cross-sectional mandrel having a side length of 15 inches. A 5 weight % KRATON D1107 adhesive solution was applied with a paint roller to the exterior of the sheet as wrapping proceeded to provide adhesive material between successive wraps. A second, 17 inch wide sheet of SPECTRA SHIELD PCR composite material was centered on the wrapped first sheet and wrapped in the

25 same manner for 18 successive wraps. The resulting band was allowed to dry at ambient temperature (approximately 70°F) on the mandrel overnight and was then removed. The 27 inch wide portion of the band was cut into at the corners a sufficient distance to produce a 17 inch wide band and eight 5 inch wide flaps (four on each side of the 17 inch wide band, two per face). The flaps were made by

30 folding the cut portions of the sheet along the band width line. The plane of each flap was perpendicular to the plane of the side of the band to which it was attached.



Four 15 inch x 14 inch rectangular fiberglass plates were glued to the inside of the four sides/faces of this band, one per face, using a polysulfide adhesive (PROSEAL 890 B-1/2, a product of Courtaulds Aerospace). Similarly, eight 3.5 inch x 15 inch rectangular fiberglass plates were glued to the inside of the flaps, one per flap. The fiberglass reinforced epoxy plates utilized were Scotsply Reinforced Composites, type 1002, crossply 0.060, a commercial product available from the 3M Corporation, and had an areal density of  $2.69 \text{ kg/m}^2$ . The band was collapsible.

A second band, 17 inches wide, was similarly wrapped 35 times around a slightly larger mandrel. A third band, also 17 inches wide, was similarly wrapped 35 times around yet another mandrel which was slightly larger than the mandrel used for the second band. Neither of these bands had flaps or fiberglass plates. Both bands were collapsible. The three bands, including the fiberglass plates, weighed a total of 12.5 kg (27.5 lb). The bands alone had an areal density of  $4.73 \text{ kg/m}^2$ . About 50 weight percent of the fibers were continuous length fibers in the hoop or band direction.

Blast resistance testing was carried out as follows. The first band of box A was placed on its side on a table, i.e., with its open sides to the top and bottom. A thin low density polyethylene plastic bag was placed completely across the bottom open side of the band. Eight ounces of C4 explosive charge were placed at the geometric center. The balance of the inside cavity was filled with BARBASOL® brand shaving cream (density of foam about  $0.053 \text{ g/c}^3$ , blowing agent isobutane), commercially available from Pfizer Inc. The slightly larger second band was then slid onto the first band with two of its opposing faces covering the originally open sides of the first band. The slightly larger third band was then slid over this assembly. When the charge was exploded, minor distortion of the container took place and venting of the container occurred over a period of a few seconds. The container was emptied, dried, and retested with 12 ounces of C4, with the cavity again filled with shaving cream (as before). The charge caused the container to rip apart.

Box B was similarly tested against 10 ounces of C4 with its cavity filled with shaving cream. Minor container distortion occurred and venting took place over a few seconds. This container was emptied, dried, and retested against 6 ounces of C4, without any shaving cream in the cavity. On explosion of the C4, fire emanated from the edges of the container. The container remained intact, but began to burn and was subsequently destroyed by the fire.

The  $C_{50}$  value for this container assembly (includes aqueous foam) was 11 ounces.

10

### EXAMPLE 11

A cubic container of 15 inch internal side length was constructed from three bands of SPECTRA 1000, 215 denier, 55 x 55 ends per inch, plain weave fabric, areal density  $0.112 \text{ kg/m}^2$  ( $3.30 \text{ oz/yd}^2$ ). In the inner band an aluminum picture frame was incorporated into each face and flaps in order to provide structural support; these were cut from 1/16 inch thick aluminum plate having an areal density of  $4.16 \text{ kg/m}^2$ . The bands were easily folded and the outer bands could also be rolled into a cylinder.

On the inner band the first four plies were cut extra wide so that flaps could be formed. Two wraps of 27 inch wide fabric were wound onto a mandrel. A square aluminum picture frame, 14.75 inches on the outside by 11.75 inches on the inside (making a frame 1.5 inches wide) was attached to each of the four sides of the band with double stick tape. These frames were to act as support for the four sides of the box. To lend some rigidity to the flaps, solid pieces of aluminum sheet were attached to the left and right of each picture frame with approximately 1/2 inch gap from the frame. These eight pieces were 14.75 x 3.0 inches in size. A set of four pieces were placed on each side of the band. In each set two plates on opposite sides of the mandrel were modified by cutting them into trapezoids with a 45 degree angle with the short side facing away from the picture frames. This allowed folding the flaps inward 90 degrees (once removed from the mandrel) to form sides of a cube without having to cut

the fabric along the edges between flaps. See FIGURES 9A - 9E and accompanying discussion, supra. To complete the inner band, two additional wraps of 27 inch wide fabric were wound around the picture frame. Twenty-one wraps of 15 inch wide fabric centered on the 27 inch wide portion, were wound onto the mandrel for a total of 25 plies. All fabric was temporarily taped together with double stick tape as needed, slipped off the mandrel and hand stitched with sewing thread (made from three ends of 215 denier SPECTRA 1000 yarn, produced by Advanced Fibers Technologies, hereafter "sewing thread" unless otherwise stated) to hold the fabric plies and the aluminum panels in place (FIGURE 9A). Mating VELCRO brand hook and loop fastening strips (1 inch x 6 inches) were sewn on along the outer edges of the flaps so that the flaps in each set of four, on the two sides of the center panels, could be attached to each other when folded inward by 90 degrees (FIGURES 9B, 9C, 9D). When this was done a free standing cubical structure was formed (FIGURE 9E). With the VELCRO fasteners released the inner band could be readily folded flat.

The middle band was made by hand winding a 15 inch wide strip of fabric around the inner band set up in form of the cube described above. Twenty-five wraps of fabric were wound. The direction of winding was over two closed sides of the inner band and over the two open sides (where flaps are located). Again the band was temporarily taped together followed by hand stitching with sewing thread along one side and once across the width. The middle band could be easily rolled up in the direction in which it had been wrapped.

The outer band was made from 25 wraps of fabric like the middle band, but the fabric strip was 16 inches wide for complete coverage of the underlying bands. It was made by wrapping the fabric over the assembled inner and middle bands. The wrapping direction was over two closed and two open sides of the inner band but perpendicular to the middle band.

Taping and stitching were done as for the middle band. The outer band could be easily rolled up in the direction in which it had been wrapped.

The assembled cubic container had a fiber areal density of twice that of the individual bands, excluding areal density contributed by the flaps. The final weights of the bands were: inner - 3.75 kg; middle - 1.77 kg; and outer - 1.87 kg; for a total weight of 7.39 kg. The aluminum sheet incorporated in the frame and flaps of the inner band formed about 1.33 kg of this total. About 50 weight percent of the fibers were continuous length fibers in the hoop or band direction.

The inner band was filled with aqueous foam (BARBASOL brand shaving cream), as in Example 10, after 113.5 grams (4 ounces) of C4 had been located at the geometric center of the band. Bands two and three were assembled over the inner band, as in Example 10, and Anderson Blastgauges were placed at 2.5 and 5 feet from the center of the container assembly and parallel to two faces to measure overpressures. {The Anderson Blastgauge gauges consist of two flat aluminum plates pierced with ten round holes of various diameters and comes with four screws and wing nuts. Standard xerox (#20 lb) copy paper is inserted between the plates and held tightly by the screws and wing nuts to create a series of paper diaphragms of ten different diameters. Overpressure is estimated by the damage to paper in the various diaphragms. }

On detonation, the cube bulged and some foam escaped from the corners of the cube, accompanied by a hissing sound which lasted for approximately 1 second after the detonation. None of the holes in the Anderson gauges showed damage, indicating the overpressure 2.5 ft and 5 ft from the container was less than 0.9 psi. In contrast, the overpressure for the unconfined charge was greater than 6.5 psi at 5 ft, between 3.2 and 5.6 psi at 7.5 ft, and between 2.0 and 3.7 psi at 10 ft. The foam did not penetrate the fabric faces of the inner band.

The container was emptied, dried, and retested with 6 ounces of C4, with the cavity again filled with shaving cream. The container assembly

contained the explosion. The container again was emptied, dried, and retested with 10 ounces of C4, with the cavity once again filled with shaving cream. Upon detonation, the container ripped apart.

The  $C_{50}$  value for this container assembly (includes aqueous foam) was 8 ounces (note that charge increments are typically smaller than in this example).

### EXAMPLES 12 - 16

In Examples 12 - 16, comparative studies were carried out on containers and container assemblies using different materials of construction for the containers, but with the identical three band design, with and without blast mitigating material (an aqueous foam). In all of these examples, the areal density of each of the three bands was  $2.8 \text{ kg/m}^2$ , overall container weight was 7.4 kg (16.3 lb), and the inner cavity (volume) was a cube with a side length of 15 inches..

Testing was carried out at H.P. White Laboratories. In cases where aqueous foam was used band 1 was placed on a table with flaps folded to provide rigidity and with the designated charge in place attached to the detonating wire (detonating wire also served to support the charge in the geometric center of the container). One open side of band 1 was in contact with the table and a low density polyethylene (LDPE) plastic bag was placed in band 1 to cover the bottom opening. BARBASOL brand shaving cream was discharged into the cavity, as in Example 10. Bands 2 and 3 were placed in position, as in the previous examples. The cubic container was placed on sawhorses and the charge detonated. A video record was obtained and in some cases overpressures at 2.5 and 5.0 ft. from the container were measured, as in Example 11. In cases where aqueous foam was not used assembly proceeded without using the LDPE bag and shaving cream.

Testing was carried out with each series of identical containers with varying charge weights with the objective of establishing a  $C_{50}$  value. A summary of blast data and  $C_{50}$  values are set forth in Tables 4 and 5, respectively.

### EXAMPLE 12

The fabric utilized in this example was a fine denier SPECTRA 1000, 215 denier, 55 x 55 ends per inch, plain weave fabric, areal density 0.112 kg/m<sup>2</sup> (3.30 oz/yd<sup>2</sup>). A series of identical fine denier fabric containers was constructed in the following manner.

a. An inner shell for band 1 was constructed by wrapping a 27 inch wide layer of the fabric around a 30 inch long plate. After two wraps aluminum picture frames and flaps were affixed with double stick tape, as in Example 11. Two additional wraps were made and the flaps and picture frames were sewn into position, as in Example 11. Mating VELCRO brand hook and loop fasteners were attached to the outside of the flaps. When the flaps were folded and the fasteners engaged the inner shell became a free standing cube. (For improved rigidity during construction a cubic mandrel was inserted into the cubic cavity for winding of bands.) The aluminum picture frames had outside side length of 14 inches and inside side length of 11 inches. Two of the flaps were rectangular in shape, with side lengths 14 x 3 inches. The other two flaps had the rectangles cut at 45 ° to form a trapezoid with longest side length of 14 inches. The weight of picture frames and flaps was 1.65 kg (3.63 lb.) Fabric, 15 inches wide, was wound around the inner shell to achieve an areal density of 2.8 kg/m<sup>2</sup> on the faces (excluding weight of the aluminum). This fabric was stitched from one side to the other with sewing thread to form band 1..

b. Band 2 was wound around band 1, as in Example 11, using 15 inch wide fabric strip. This band was sewn from one side to the other with sewing thread as in Example 11 to create a coherent band.

c. Band 3 was wound around bands 1 and 2, as in Example 11, and sewn in a similar manner to band 2.

Test results and C<sub>50</sub> values are set forth in Tables 4 and 5, respectively.

### EXAMPLE 13

Example 12 was repeated with the following changes. The material used to form the bands was a coarser denier SPECTRA 900, 1200 denier, 21 x 21 ends per

inch, areal density  $0.228 \text{ kg/m}^2$ , plain weave fabric. To create the inner shell for this example, only one wrap of the 27 inch wide strip was made before the picture frame and flaps were attached. One more wrap of the 27 inch wide fabric was made and the picture frames and flaps were sewn between the two layers. Test results and  $C_{50}$  values are set forth in Tables 4 and 5, respectively.

#### EXAMPLE 14

Example 12 was repeated with the following changes. The material used to form the bands was SPECTRA SHIELD composite, described in Example 2 above, and having an areal density of  $0.134 \text{ kg/m}^2$ . About 50 weight percent of the fibers were continuous length fibers in the hoop or band direction. The containers were constructed in the following manner:

- a. An inner shell was constructed of fine denier fabric, picture frames and flaps, as in Example 12.
- b. Band 1 was constructed by wrapping a 15 inch wide SPECTRA SHIELD composite strip around a 30 inch long aluminum plate having a thickness of 0.125 inch. Aluminum plates, 14 x 18 inches, were used to create the band with the 18 inch dimension of these plates corresponding to and overlapping the 15 inch width of the composite strip. These plates were placed on the strip so that 0.5 inch gaps were left at either end of the length and a one inch gap was left in the center of the length. The plates were placed on either side of the composite strip wrap, in opposition, for molding.
- c. The band was molded in a hydraulic press under a force of 10 tons at a temperature of about  $125^\circ\text{C}$  for a time period of about 30 minutes to produce four consolidated faces, 15 inches wide x 14 inches long (in the hoop or band direction), separated by four unconsolidated edges (15 inches wide x 1 inch long). The four unconsolidated edges corresponded to the gaps between the four plates.
- d. Band 1 was removed from the aluminum plate and snapped into cubic shape. The inner shell was coaxially inserted into band 1.
- e. Band 2 was wound around a 30.75 inch long plate and molded in an identical manner to band 1 except that the gaps were correspondingly larger.

f. Band 3 was wound around a 31.25 inch long plate and molded in an identical manner to band 1 except that the gaps were correspondingly larger.

Test results and  $C_{50}$  values are set forth in Tables 4 and 5, respectively.

5

#### EXAMPLE 15

Example 14 was repeated with the following changes. The material used to form the bands was a SPECTRA prepreg sheet (unidirectional sheet commercially available from AlliedSignal Inc., areal density 0.067 kg/m<sup>2</sup>). The containers were constructed in the same manner except that two wraps of SPECTRA SHIELD composite strip were used at the beginning and end of each band. Band 1 contained 78 weight percent unidirectional tape and 22 weight percent SPECTRA SHIELD. Bands 2 and 3 contained 81 weight percent unidirectional tape and 19 weight percent SPECTRA SHIELD. About 90 weight percent of the fibers were continuous length fibers in the hoop or band direction. Test results and  $C_{50}$  values are set forth in Tables 4 and 5, respectively.

15

#### EXAMPLE 16

Example 12 was repeated with the following changes. The material used to form the inner shell and bands was a coarse (3000) denier KEVLAR® 129 aramid woven fabric, areal density 0.446 kg/m<sup>2</sup>, Style 745, 17 x 17 ends per inch. Test results and  $C_{50}$  values are set forth in Tables 4 and 5, respectively.

20

#### EXAMPLE 17

In this example, a series of four boxes were made for comparative studies as follows. A linear low density rotationally molded polyethylene cube weighing 4.5 kg (9.9 lb) and having a side length of 17 inches was placed between two plates on an Entec filament winder. A seventeen inch wide strip of unidirectional tape precursor for SPECTRA SHIELD PCR (areal density 0.0675 kg/m<sup>2</sup> with 80 weight percent SPECTRA 1000 fiber and 20 weight percent KRATON D1107 matrix) was wound nine times around four sides of the cube by rotating the cube around its x axis. As the unidirectional tape was wound an adhesive layer (5

25

30



weight percent KRATON D1107 in toluene) was applied to the surface with a paint roller. The cube was rotated at the rate of 2 to 3 rotations per minute and stopped intermittently as necessary to apply the adhesive. The process was first repeated by rotating the cube around its y axis and finally by rotating the cube  
5 around its z axis. A second set of three bands of 9 wraps was repeated with the identical sequence (x then y then z) of wrapping directions. A 2.5 inch square was cut from one face near one corner. The sides of the square hole were parallel to the sides of the face and 2 inches from two of the adjacent edges. The wrapped container weighed 7.6 kg (16.7 lb), and the wrapping material had an areal density  
10 of 2.43 kg/m<sup>2</sup>. To be able to close the hole during the blast, an aluminum plate, 3 x 5 x 0.25 inch in size, was inserted diagonally into the box through the hole. For alignment, a square plywood plate, 2.4 x 2.4 x 0.25 inch, was centrally affixed to the aluminum plate with double stick tape. A paper clip loop was threaded through two holes, 0.0625 inch in diameter, drilled through the plywood and aluminum  
15 plates. A 0.25 inch diameter nylon tube was inserted through the loop to fix the plate in position. A small hole (0.0625 inch) was drilled in the center of the adjacent side for placement of the detonation wire. Two strips of SPECTRA SHIELD (3 inches wide and corresponding in length to 9 wraps) were wrapped around each cube over the aluminum plate held in register in the square hole. The  
20 two strips were parallel to the edges of the cube and their length directions formed a right angle over the square hole. Duct tape was used at the beginning, middle and end of each strip to secure the resulting band. Thus, there were 2 mutually perpendicular bands placed around the container that both covered the access hole.

Three of the containers, with no blast mitigating material located therein,  
25 were tested against C4 charges of 28 (1 oz), 43 (1.5 oz), and 57 g (2 oz), respectively. The two containers tested at the lower charge weights each contained the charge (passed), while the container tested at 57 g (2 oz) charge weight ruptured with rips of 3.5 and 6 inches on different edges of the cube.

The fourth container was filled with GENETRON 134A, a condensable gas  
30 (1,1,1,2-tetrafluoroethane) commercially available from AlliedSignal Inc., and tested against a C4 charge of 57 g (2 oz). The container remained intact.

**EXAMPLE 18**

Two series of fabric tubes were prepared, one utilizing SPECTRA 1000 fiber (Style 952, Clark Schwebel, 34 x 34 ends per inch, plain weave, areal density 0.204 kg/m<sup>2</sup>) and the other utilizing KEVLAR 29 yarn (Style 728, Clark Schwebel, 17 x 17 ends per inch, plain weave, 1500 denier, areal density 0.226 kg/m<sup>2</sup>). Each tube was prepared as follows:

- a. A 36 x 15 inch wire mesh (mesh openings 0.5 inch) was wrapped on a square wooden mandrel of side length 7.5 inches. The ends of the wire mesh overlapped and were taped together.
- b. Fabric, 15 inches in width, was wrapped around the wire mesh frame a sufficient number of times to achieve a fabric areal density of 3.1 kg/m<sup>2</sup>.
- c. The assembly was slipped off the mandrel.
- d. The fabric wrap was sewn together by sewing through all layers from one side of the tube to the other. KEVLAR 29 sewing thread was used to hand stitch a continuous seam.

The four identical tubes made from SPECTRA fiber were designated S1, S2, S3 and S4. The four identical tubes made from KEVLAR 29 fiber were designated K1, K2, K3 and K4.

Testing against spherical charges of TRENCHRITE-5 in the geometrical center of the tubes was carried out as in Example 5. Tubes S4 and K4 both were filled with an aqueous foam, BARBASOL brand shaving cream, having a specific gravity of 0.053 g/cm<sup>3</sup>. Test results are presented in Table 6.

A C<sub>50</sub> value for the SPECTRA fabric tubes was calculated to be 2.63 ounces. A charge of 3 ounces of TRENCHRITE 5 was used with Tubes S2 and S4. Tube S4 provided significantly better blast resistance than S2 because it was filled with an aqueous foam. Close examination of a video of tubes S2 and S4 indicates that the fire-ball observed in S2 is completely suppressed in S4 and that foam is blown out of the ends of S4. Examination of the tubes after testing indicated that Tube S4 showed less damage than all the other tubes, including tube S1 which had a charge of 1.5 ounces, one-half that of S4.

A  $C_{50}$  value for the KEVLAR fabric tubes was calculated to be 2.5 ounces. A charge of 4 ounces of TRENCHRITE 5 was used with Tubes K2 and K4. Tube K4 showed significantly less damage because it was filled with the aqueous foam.

5

### DISCUSSION OF EXAMPLES 1 - 9

The examples demonstrate that cubic containers constructed from three mutually supporting four-sided bands provide outstanding blast resistance. Example 2's Box 2 of side length 15 inches was able to contain almost as large an explosive charge as the control cubic container of Example 1 of side length 31  
10 inches and having almost an identical areal density (made utilizing SPECTRA SHIELD composite panels). Thus, similar performance is obtained using a box significantly lighter and smaller than that of the control, i.e., 1/4 the weight of the control and containing 1/8 the volume. In addition, the boxes designed in  
15 not have steel hinge pins which can act as long rod penetrators during an explosive event. It is interesting to note that the box of the comparative example utilizing SPECTRA SHIELD composite panels outperformed the box utilizing KEVLAR composite panels.

Examination of the boxes of Example 2 after explosive testing, coupled  
20 with evaluation of high speed photography results, indicated that container failure did not occur by "shock holing" (rupture caused by the impulse of the shock wave against the container wall). Shock holing would have caused rupture of the containers at the center of the faces of the cube. In no case was this observed; failure occurred along the edges of the boxes. During the explosive event, the  
25 bands of these boxes distorted and allowed venting of gases. The flaps of the flapped boxes helped to control, but did not eliminate, the venting of hot gases. In order to further reduce such venting the inner band was made more rigid in Example 3 by incorporating a rigid epoxy inner shell. This container easily contained 6 ounces of explosive, with minimum distortion, no rapid venting and  
30 essentially no visible permanent damage to the structure.

With reference to Examples 5-7 and Tables 1 and 2, it can be seen that failure of the square cross-sectional tubes occurred by breaking fibers along the length of the edges. These tears were oriented in parallel to the length of the tubes, which is essentially perpendicular to the hoop direction of the tube. By increasing the fraction of substantially continuous fiber in the hoop direction of the tube (Example 5 vs. Example 6) the ballistic performance of the tube was increased. A fiber fraction increase of 50% resulted in a 50% increase in the  $C_{50}$  value.

The results set forth in Tables 1 and 2 also clearly show that the square cross-sectional tube was more blast resistant than the circular cross-sectional tube. The square cross-sectional tube distorted to a more nearly circular cross-sectional shape, which resulted in an increase in cross-sectional area, and thus an increase in internal volume of the tube by as much as 30%. It is believed that this effectively lowered the strain rate to which the fibers were subjected, and that this response decreased the rate of the application of high tensile force and decreased its magnitude.

With reference to Table 3 and the data set forth regarding square cross-sectional tubes, it can be seen that less damage occurred with shorter overall tube lengths and when the SPECTRA SHIELD fibrous layers were consolidated using heat and pressure rather than an adhesive solution.

In all of the tubes, the tear direction was parallel to the length of the tubes. Consequently, in Example 9, the tear length is limited by wrapping the tubes in the hoop direction with bands of a reinforcing unidirectional strip (mini-bands). Limiting the length of the tears that form is expected to limit the rate of gas escape to thereby make tubes and containers constructed according to this principle more resistant to catastrophic failure.

#### **DISCUSSION OF EXAMPLES 10 - 16, 17 AND 18**

In all cases the blast mitigating material (aqueous foam) improved the efficiency of the blast resistant container significantly. The temperature of the constrained foam was raised significantly above the ambient temperature of about

25°C. Typically, foam temperature was 70°C when measured in a container assembly which had withstood the explosion of 170 g (6 ounces) of C4.

Example 11 shows that aqueous foam not only mitigates blast, but also prevents fire. At a charge level approximately one-half of the  $C_{50}$  of the container plus foam assembly, there was significant container damage, followed by a fire which destroyed the container.

Examples 12 - 16 show that the aqueous foams play a critically important role in providing blast protection, providing protection against explosive charges weighing 2 to 4 times that of what can be contained without foam. These examples further show that coarse fabric constructed from higher denier SPECTRA 900 yarn gives similar blast protection to the considerably more expensive fine fabrics utilizing lower denier SPECTRA 1000 yarn. All of these examples included containers that were collapsible when empty, i.e., without blast mitigating material therein. These are especially useful in space constrained environments.

Example 17 illustrates that blast resistance is improved when air is replaced with a low sonic velocity, condensable gas, in combination with a non-collapsible container having bands and a door for closure. In addition to mitigating shockwaves from the explosion, certain of these gases can also curtail the oxidation process and prevent fires.

Example 18 illustrates that advantages achieved in closed containers by the use of aqueous foams may also be realized in blast directing tubes.

From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions.

Table 1

Blast Data for Tubes

<u>Example</u>	<u>Tube</u>	<u>Charge (oz.)</u>	<u>Results*</u>
5	A	8	one failure, 6" tear on edge
5	B	4	no failures
5	C	6	one failure, 3" tear on edge
5	D	6	no failures
6	A	9	no failures
6	B	13	two failures, 11" tear on edge and 12" tear on edge
6	C	11	two failures, 6" tear on edge and 4" tear on edge
6	D	10	one failure, 6" tear on edge
7	A	12	six failures, tears of 22", 20", 8", 8", 22" and 5"
7	B	8	six failures, tears of 1", 3.5", 1.5", 15", 3", 13"
7	C	4	one failure, 2.5" tear
7	D	2	no failures

\* All tears were oriented in parallel to the length of the tubes.

Table 2

Comparison of Blast Resistance of Different Tubes

<u>Example</u>	<u>Cross-Sectional Shape</u>	<u>Fraction Continuous Fibers Hoop Direction</u>	<u>C<sub>50</sub> (oz.)</u>
5	Square	0.50	6.0
6	Square	0.75	9.5
7	Circular	0.50	3.0

Table 3Example 8 Tube Blast Data for 2 Ounce Charge

<u>Series</u>	<u>Tube Length (inches)</u>	<u>Results*</u>
1(adhesive)	15	one failure, 4" tear on edge
2(adhesive)	22.5	two failures, 3.5" tear on edge and 1.75" tear on edge
3(pressed)	15	one failure, 2.5" tear on edge
4(pressed)	22.5	one failure, 3.75" tear on edge

\* All tears were oriented in parallel to the length of the tubes.

**Table 4**  
**Blast Data for Examples 12-18**

<u>Example</u>	<u>C4 Charge Weight (g/oz)</u>		<u>Results*</u>
	<u>Air</u>	<u>Foam</u>	
12	85/3.0	---	Fail
12	---	170/6.0	Pass
12	---	227/8.0	Fail
13	43/1.5	---	Pass
13	71/2.5	---	Fail
13	---	142/5.0	Pass
13	---	170/6.0	Fail
14	43/1.5	---	Pass
14	71/2.5	---	Fail
14	---	199/7.0	Pass
14	---	227/8.0	Fail
15	43/1.5	---	Pass
15	71/2.5	---	Fail
15	---	170/6.0	Pass
15	---	227/8.0	Fail
16	43/1.5	---	Fail
16	---	170/6.0	Pass

\*Pass-Container/Container Assembly contained charge.  
Fail-Container was ruptured.

5

10

15



Table 5

Comparison of Blast Resistance for Examples 12-16

<u>Example</u>	<u>Air/Foam</u>	<u>Fraction Continuous Fiber Hoop Direction</u>	<u>C50 (g/oz)*</u>
12	Air	0.50	<85/<3.0
12	Foam	0.50	199/7.0
13	Air	0.50	57/2.0
13	Foam	0.50	156/5.5
14	Air	0.90	57/2.0
14	Foam	1.00	213/7.5
15	Air	0.50	49.7/1.75
15	Foam	0.50	199/7.0
16	Air	0.50	<43/<1.5
16	Foam	0.50	>170/>6.0

\*Average of highest passing weight of charge and lowest failing charge weight.

Table 6Blast Data for Example 18

<u>Sample</u>	<u>Explosive Charge (oz)</u>	<u>Results</u>
S1	1.5	Pass-No penetrations/splits/tears
S2	3.0	Fail-4" rip at corner seam
S3	2.25	Pass-No penetrations/splits/tears
S4*	3.0	Pass-No penetrations/splits/tears
K1	2.0	Pass-No penetrations/splits/tears
K2	4.0	Fail-Severe rips/tears
K3	3.0	Fail-Rips/tears 5" and 8"
K4*	4.0	Fail-Rips/tears 3.5" and 10.5"

\*Filled with blast mitigating material (aqueous foam)